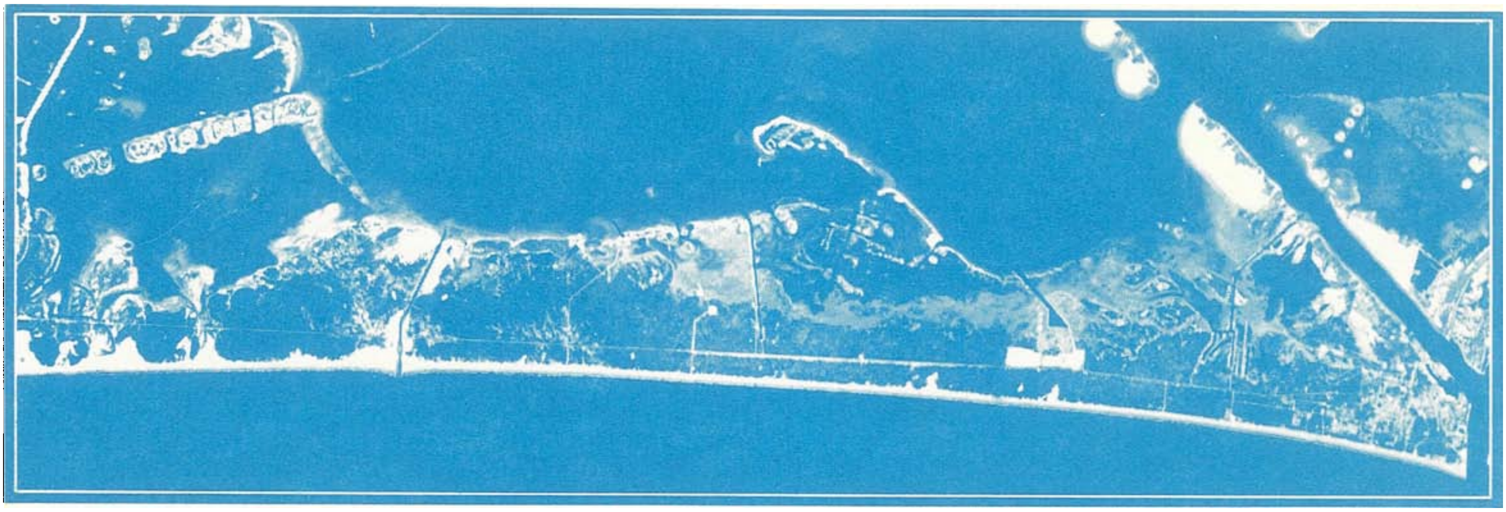
Report of Investigations No. 92

# Land and Water Resources, Historical Changes, and Dune Criticality:

## Mustang and North Padre Islands, Texas



by William A. White, Robert A. Morton,
Ralph S. Kerr, W. David Kuenzi, and William B. Brogden

1978 / BUREAU OF ECONOMIC GEOLOGY • W.L. FISHER, DIRECTOR
THE UNIVERSITY OF TEXAS AT AUSTIN • AUSTIN, TEXAS 78712

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## PLATE 1

Land and water resources, Mustang and north Padre Islands, Texas . . . . . in pocket

## INTRODUCTION

Barrier islands along the Texas Coastal Zone are part of a complex and dynamic system represented by many distinct yet interrelated environments affected by a variety of natural processes, climatic conditions, and human activities. Because of the increasing realization that island resources are extremely important both as natural systems and as valuable recreational areas, the necessity of understanding their complexities and how man and his activities interact with them becomes more and more urgent.

This report, which focuses on a 20-mile segment of barrier islands along the Texas coast, treats several aspects of the islands including land and water resources, active processes and natural hazards, historical changes in natural environments, historical changes in Gulf and bay shorelines, and the importance of fore-island dunes. A comprehensive understanding of these topics is important because essentially they govern the natural capability and limitations of barrier islands to support productive future development.

## GENERAL SETTING

Mustang and Padre Islands are barrier islands located along the southern portion of the Texas Gulf Coast. The islands are bound by the waters of Corpus Christi Bay and Laguna Madre to the west and northwest and by the Gulf of Mexico to the east and southeast. The area encompassed by this investigation includes all of Mustang Island, the northern tip of Padre Island, and adjacent bay and lagoon environments—a total area of approximately 50 square miles, all of which is within Nueces County (fig. 1). The northern boundary of the study area is defined by the Corpus Christi Ship Channel and Aransas Pass, and the southern boundary is defined partly by the Nueces-Kleberg County line. The distance between these two defining lines is approximately 21 miles. The Corpus Christi Bay shoreline and the Intracoastal Waterway mark the landward margin of the study area. A prominent feature along the bay shoreline of Mustang Island is Shamrock Island, a recurved spit extending southwestward into Corpus Christi Bay (fig. 1).

Natural features on and near Mustang and north Padre Islands include beaches, vegetated dunes and barrier flats, active dunes and blowouts, tidal flats, storm-washover areas, marshes, marine grassflats, and bay-margin sands and shoals. The general relationships of these natural environments with respect to each other and with respect to Gulf and bay waters are depicted in figures 2 and 3. The island environments are affected by a variety of natural active processes and hazards, including waves and longshore currents, tidal currents, eolian processes, tropical storms and hurricanes, and subsidence and sea-level rise.

Major cultural features on Mustang and north Padre Islands include the small community of Port Aransas located on north Mustang Island and a recreational community development on north Padre Island. Public recreational areas include Mustang Island State Park, Nueces County Park, Packery Channel Park, and Port Aransas Park. Water Exchange Pass, called the fish pass (pl. 1), connects Corpus Christi Bay with the Gulf in the vicinity of Mustang Island State Park. Access to the islands is provided by ferries operating across the Corpus Christi Ship Channel near Port Aransas and by the John F. Kennedy causeway that connects the city of Corpus Christi and the mainland to north Padre Island. Park Road 53 extends the entire length of Mustang Island connecting north Padre Island with Port Aransas. Public access to the Gulf beach is provided by this highway, and vehicular traffic is presently permitted along the entire stretch of beach.

Mustang and north Padre Islands lie within a climatic area termed dry subhumid by Thornthwaite (1948). Mean annual precipitation ranges between 30 and 32 inches per year, and mean annual evaporation averages near 30 inches per year (Carr, 1967; Arbingast and others, 1967). Droughts are not uncommon. Winds play an extremely important role in shaping and modifying island environments. Onshore southeasterly winds prevail during most of the year but are replaced periodically by strong and dominant north winds associated with frontal passages during winter months.

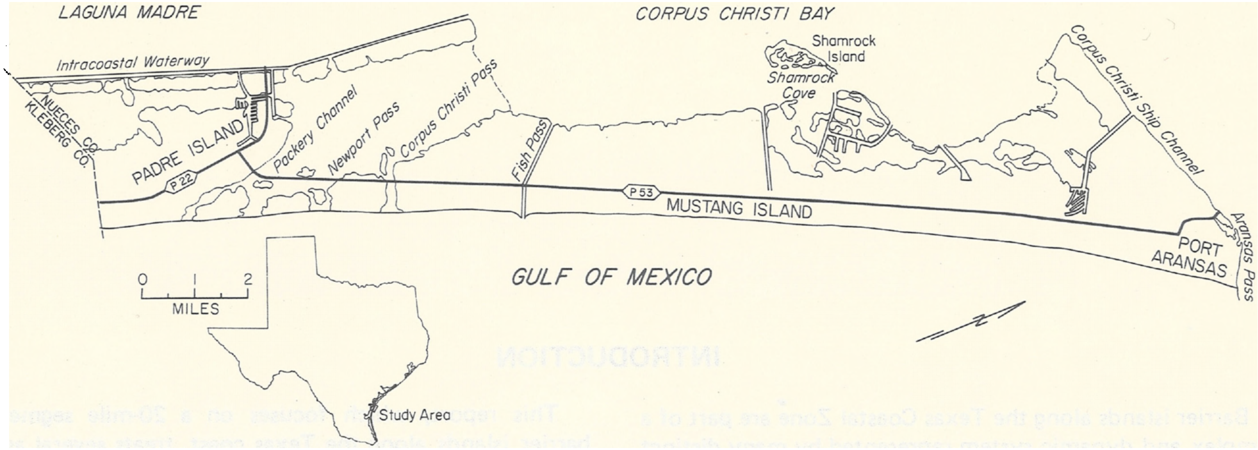



Figure 1. Locality map of Mustang and north Padre Islands.

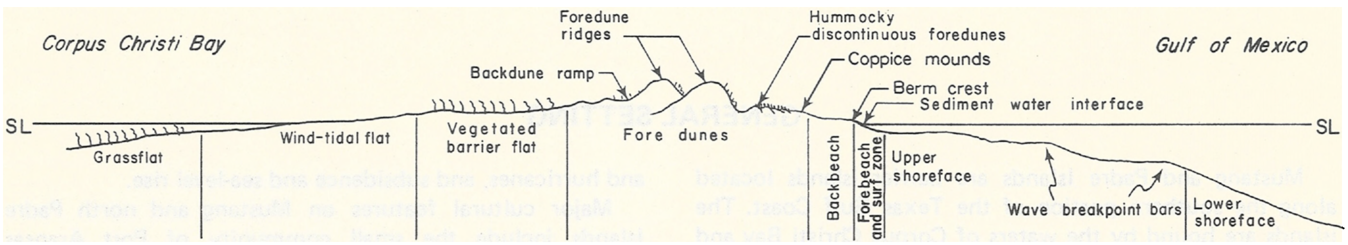



Figure 2. Generalized diagram of barrier islands along the Texas coast. (Modified from Scott and others, 1964.)

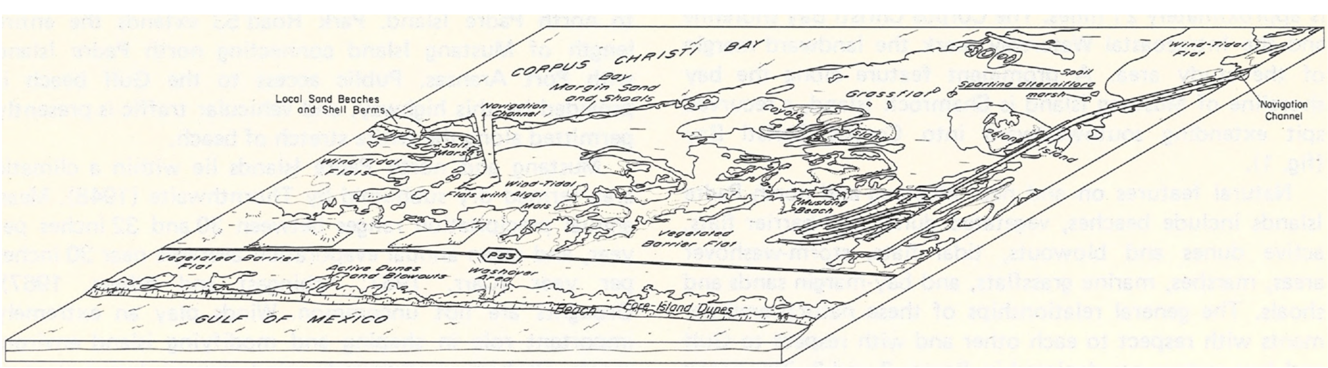



Figure 3. Generalized diagram of barrier island land and water resource units.

## DELINEATION OF LAND AND WATER RESOURCES

In 1969, the Bureau of Economic Geology began a comprehensive inventory of the Texas Coastal Zone (Fisher and others, 1972; Brown and others, 1976). Experience and knowledge gained from the Coastal Zone project provided the foundation from which the concept of resource capability was developed. The concept evolved from the realization that (1) productive utilization of land and water resources can be maximized and environmental problems minimized if utilization of resources—land, water, and biota—is consistent with their natural capabilities and limitations and (2) capabilities and limitations depend on (a) the physical, chemical, and biological properties and active processes that characterize the resources, as well as (b) the kinds and intensities of resource use.

As originally defined by Brown and others (1971), resource-capability units are environmental entities—land, water, area of active process, or biota—defined in terms of the nature and degree of activity or use they can sustain without losing an acceptable level of environmental quality. Although the definition in theory is sound, practical application of the concept of resource capability first requires delineation of land and water resource units on the basis of distinctive characteristics that can be identified and mapped.

Thus, a modified definition was proposed by St. Clair and others (1975): land- and water-resource units (resource-capability units) are mappable entities, either natural or man-made, that are defined by the physical, chemical, and biological characteristics or processes which govern the type and degree of use that is consistent both with their natural quality and productive utilization.

Units are established by recognizing elements of first-order environmental significance (Brown and others, 1971). First-order elements are those physical, biological, chemical, and/or active-process elements that are of primary significance in affecting current and potential land use.

As a simplified example of how these first-order elements are recognized, assume that highly permeable sand has been mapped at the surface in two different areas along the Coastal Zone. One area is on the mainland where the sand, a Pleistocene distributary channel sand, is penetrated by water wells that produce fresh water from the shallow fresh-water aquifer for domestic and irrigation purposes. Because the substrate is highly permeable sand, it allows rapid infiltration of rainwater which recharges the shallow aquifer. Of first-order significance are (1) the high permeability of the unit and (2) the fact that the unit serves as a recharge zone and local aquifer. The mapped unit would be classified as a geohydrologic unit and called a recharge sand.

Assume that the second area of highly permeable sand composes part of a barrier island which is commonly washed over by storm waters. In this case, the mappable washover sand unit would be classified on the basis of its storm-washover potential which is considered to be the overriding environmental factor governing use of this area; the highly permeable nature of the sand is of secondary importance in this case. The mapped area is classified as a process unit known as a storm-washover area.

A land-resource unit, such as the washover sand, may be recognized and mapped by aerial photographic interpretation. Criteria may include (1) absence of protective fore-island dunes gulfward of the sand area, (2) generally flat topography with low elevations, (3) water ponded in scoured channels, (4) absence of barrier-flat vegetation, and (5) presence of scattered marsh plants and local algal mats. Recognition of these criteria helps confirm the probability that the area links Gulf and bay waters during storms. Aerial photographic interpretations, supported by field observations, published studies and maps, and historical records aid in accurately determining first-order environmental factors.

Land- and water-resource units derived by this type of first-order environmental analysis may be classified into (1) physical units (geologic substrate and soil units) where physical properties are of primary importance; (2) geohydrologic units where high permeabilities enhance aquifer recharge; (3) process units such as beaches, washover areas, floodplains, and active dunes where active physical processes are of first-order significance; (4) biophysical units such as vegetated fore-island dunes where physical characteristics such as height, location, continuity, and vegetation stabilization are of primary importance; (5) biologic units such as grassflats and salt marshes where biologic activity is the dominant factor; and (6) man-made units such as spoil, made land, and dredged channels where human activity has resulted in important environmental modification.

Evaluation of natural-resource units also depends on response to various types and intensities of activities that occur on the land and in or on the water. Present and anticipated land and water uses are varied, but certain activities serve as examples. These are (1) solid and liquid waste disposal; (2) channelling, ditching, and draining; (3) constructing of buildings, highways, light and heavy industry, jetties, groins, piers, and seawalls; (4) extracting surface and subsurface raw materials; (5) filling and land reclamation; (6) devegetating and other alteration of natural flora; (7) farming and grazing; (8) use of herbicides, pesticides, and insecticides; and (9) impounding surface water for future use or storage of wastes. Thus, the natural characteristics and carrying capacities of different areas are related to the kinds and rates of activities that they may be called on to support.

The concept of biotopes is an old concept that was first adopted for use in Texas by Oppenheimer and Gordon (1972) as a way of presenting the aesthetic, biologic, and physiographic conditions that result naturally or under man's influence in the Coastal Zone. A biotope is defined as a biological assemblage that occurs within an area of uniform environmental conditions (Kuehler, 1967). Although the biological environment may appear diverse and without pattern, there are recognizable biological assemblages that have some degree of relationship in their composition. Included within the concept is the realization that biological assemblages, particularly plant assemblages, can occur as a natural succession of communities within the given set of environmental conditions (Allee and Schmidt, 1951).

Biotopes provide a flexible basis for evaluating and comparing environmental settings of any locality. A list of applicable biotopes with their descriptions can be presented in terms of original distribution, biotope changes, and postchange pictures. From this, species compositions and the responses of the various organisms can be determined. As such, the biotope concept provides a mechanism to assess the magnitude of many environmental changes and the extent to which use changes will be felt by the biological assemblages in the Coastal Zone.

## LAND AND WATER RESOURCES OF MUSTANG AND NORTH PADRE ISLANDS

Land and water resources of Mustang and north Padre Islands were mapped jointly by personnel from the Bureau of Economic Geology and the Marine Science Laboratory at Port Aransas by combining the concepts of resource capability (Brown and others, 1971) or land- and water-resource units (St. Clair and others, 1975) and biotopes (Oppenheimer and Gordon, 1972) to produce a single map (see accompanying Land and Water Resources Map (pl. 1)). Land- and water-resource units were identified and mapped on black-and-white aerial photographs (scale approximately 1:25,000, taken in June, 1974) provided by the General Land Office of Texas. Boundaries of mapped units were transferred from photographs to a base map prepared by the cartographic staff of the Bureau of Economic Geology from U.S. Geological Survey topographic maps (scale 1:24,000).

Procedures used in mapping land and water resources were patterned after those established by the Bureau of Economic Geology in the Environmental Geologic Atlases of the Texas Coastal Zone (Fisher and others, 1972; Brown and others, 1976). These principles include: (1) extensive aerial photographic interpretation, (2) field checks, (3) aerial reconnaissance, and (4) utilization of published data. To support mapping of the land and water resources, the Marine Science Laboratory assembled a collection of several hundred low-level, oblique 35 mm photographs, both color and infrared (IR). In addition to 1974 photographs, aerial photographs ranging in date from 1938 to 1970 which were collected by the Bureau for historical monitoring were studied to help define the areal extent of some resources. These older photographs were particularly useful in identifying dredged channels and sites of disposed spoil.

In areas where a conflict between the concepts of

Table 1. Areal extent and percentage of total land and water resources, Mustang and north Padre Islands (1974).*

| Land and Water Resources | Area (acres) | Total Area (%) |
|---|---|---|
| Beach, coppice mounds, and wind-shadow dunes | 614 | 1.9 |
| Vegetated fore-island and back-island dunes | 1,502 | 4.7 |
| Vegetated barrier flats | 8,589 | 26.8 |
| Active dunes and sand blowouts | 596 | 1.9 |
| Washover areas | 1,532 | 4.8 |
| Wind-tidal, tidal, and shallow subaqueous flats | | |
| sand flats | 2,656 | 8.3 |
| algal flats | 2,056 | 6.4 |
| salt marsh | 95 | 0.3 |
| Salt marshes—*Spartina alterniflora* dominant | 178 | 0.5 |
| Salt marshes—*Spartina alterniflora* sparse or absent | 1,812 | 5.7 |
| Grassflats | 6,034 | 18.8 |
| Local sand beaches and shell berms | 54 | 0.2 |
| Bay-margin sand and shoals | 871 | 2.7 |
| Subaerial spoil and made land | 3,760 | 11.7 |
| Subaqueous spoil | 888 | 2.8 |
| Navigation channels and permanent surface-water bodies (Does not include Corpus Christi Bay, Intracoastal Waterway, or Corpus Christi Ship Channel.) | 816 | 2.5 |
| TOTAL | 32,053 | |

*Areas were calculated on the Land and Water Resource Map (scale = 1:24,000) by using a square-count method; smallest squares used were equivalent to 0.23 acres.

resource capability and biotopes arose, the unit of primary environmental significance took precedence over the one of secondary importance. For example, in areas where the resource capability classification indicated a storm washover, this classification overrode the biotope designation of sand flat and, in some areas, salt marsh. In other areas, the biotope designation of salt marsh (other than *Spartina alterniflora*) took precedence over the resource capability designation of local sand beaches and shell berms.

Land- and water-resource units are identified on the map by a distinct shade or pattern. In the case of the resource unit—wind-tidal, tidal, and shallow subaqueous flat—line patterns were employed to designate those areas where the biotopes—algal flats and salt marsh (excluding *Spartina alterniflora*)—were present on wind-tidal flats. The remaining area on these flats (those with no line pattern) corresponds to a sand-flat biotope.

Sixteen distinct land- and water-resource units were identified and mapped, and the areal extent of each was determined (pl. 1; table 1). The following discussion treats each resource unit in terms of (1) a general definition, (2) physical characteristics such as areal extent and distribution, topography, and composition, (3) natural active physical processes that affect the unit, (4) typical vegetation and/or animals, and (5) importance and/or special concerns.

## BEACHES, COPPICE MOUNDS, AND WIND-SHADOW DUNES

*General definition.*—This resource unit lies along the Gulf side of the barrier islands and includes the forebeach, berm, backbeach, and partially vegetated eolian dunes and mounds (coppice mounds and wind-shadow dunes, fig. 4) that are present seaward of the well-vegetated dunes and barrier flats (figs. 2 and 3). On the southern half of the map, it includes relatively large, partly vegetated dunes that are present seaward of well-vegetated fore-island dunes. These dunes are similar in size to the well-vegetated dunes, but because of sparser vegetation they were mapped with the coppice mounds and wind-shadow dunes. Small sand blowouts and washovers that are present along the seaward side of the fore-island dune system were mapped with the beach resource unit for cartographic simplicity.

*Physical characteristics.*—The width of the beach, coppice mounds, and wind-shadow dunes, determined at high tide, averages approximately 245 feet, with a maximum near 600 feet, including spoil placed on the backbeach adjacent to the Water Exchange Pass (or the fish pass) and a minimum of 100 feet, seaward of a seawall on north Padre Island. There are 20.7 linear miles of beach along the Gulf shoreline. Elevations range from sea level along the seaward edge of the forebeach to about 10 feet at the crest of eolian dunes and mounds. The total area represented by this resource is 614 acres (table 1). Beaches and coppice mounds are composed primarily of sand and scattered shells.

Beach width appears to increase southward within the mapped area (pl. 1) because of increased width of unvegetated dunes to partially vegetated dunes and sand mounds. The width of the beach, however, generally decreases southward from Port Aransas.

Figure 4(a)

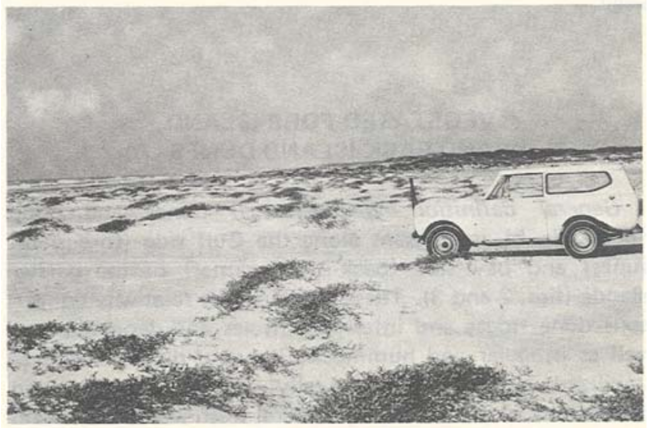


Figure 4(b)

Figure 4. (a) Beach along central Mustang Island covered with *Sargassum*. (b) Coppice mounds and wind-shadow dunes just south of the fish pass.

*Active processes.*—The beach is a zone of high physical energy. The lower beach is subject to daily wave swash and tidal inundation; the backbeach and adjacent dunes and mounds are subject to inundation and alteration by spring and storm tides as well as alteration by wind action. As a result of erosion and deposition during storms, the normal profile of beach and adjacent dunes may be altered to a broad, smooth gulfward-sloping surface. In time, as normal processes are resumed, the characteristic berm, coppice mounds, and wind-shadow dunes will be reconstructed. Additional information on Gulf shoreline changes is presented in the section on historical monitoring.

*Vegetation/animals.*—Sand mounds and dunes that are present between the back beach, and well-vegetated fore-island dunes are sparsely to moderately well vegetated. Common plants include *Ipomoea pes-caprae* (goatfoot morning glory), *Ipomoea stolonifera* (fiddle leaf morning glory), *Panicum amarum* (bitter panicum), *Uniola paniculata* (sea oats), *Croton punctatus* (beach tea), and *Sesuvium portulacastrum* (sea purslane).

*Importance/special concerns.*—The beach is an important recreational resource. Furthermore, it acts as a source of sand for fore-island dunes, helps dissipate wave and current energy, and is a habitat for some organisms.

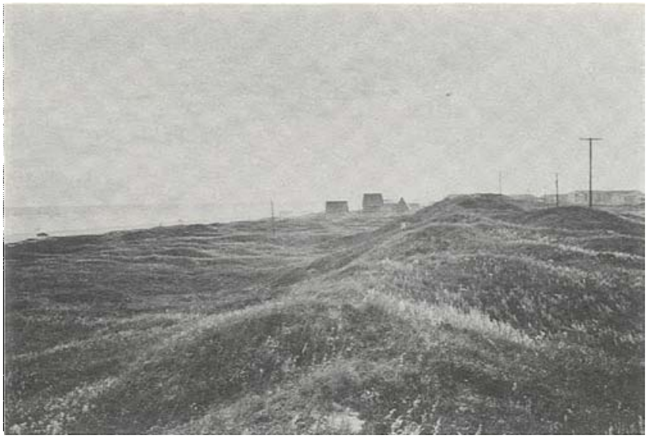


Figure 5. Well-vegetated fore-island dune ridge on north Mustang Island.

## VEGETATED FORE-ISLAND AND BACK-ISLAND DUNES

*General definition.*—Well-vegetated dunes and dune ridges (fig. 5) are present along the Gulf side (fore-island dunes) and bay side (back-island dunes) of the barrier islands (figs. 2 and 3). These areas include relatively continuous dune ridges and interlying swales and depressions as well as irregular and hummocky blowout dune complexes stabilized by vegetation. Locally, interlying swales and depressions may maintain ephemeral fresh-water ponds and marshes. Only major back-island dune systems were mapped; others were grouped with the vegetated barrier flats.

In a few areas, dunes that were once active and are now only moderately well vegetated are included in this unit; an example occurs approximately 0.1 mile south of the fish pass. Field inspection in the summer of 1974 revealed that fore-island dunes at this location were vegetated almost entirely with *Croton punctatus* (beach tea), whereas a wider diversity of plants is represented on well-vegetated fore-island dunes.

*Physical characteristics.*—More than 16 linear miles of fore-island dunes are present in the mapped area. Fore-island and back-island dunes cover approximately 1,500 acres (table 1). Elevations range from slightly more than 35 feet at the crests of the highest fore-island dunes to less than 5 feet in the interlying swales and depressions. The dunes are composed of fine-grained sand.

The width of the fore-island dune complex ranges from a minimum of about 50 feet to a maximum of about 2,000 feet. The average width is approximately 700 feet.

Fore-island dunes mapped near Port Aransas include a rather broad expanse of smaller vegetated dunes that lie between the beach and main dune-ridge complex. Relatively rapid accretion attendant with migration of Aransas Pass and construction of the Corpus Christi Ship Channel jetties has prevented the formation of larger dunes. The wide area (2,000 feet) of fore-island dunes just north of Corpus Christi Pass includes a revegetated dune and blowout system that extends bayward from the primary (gulfward) line of fore-island dunes.

*Active processes.*—Active processes may periodically affect these vegetated areas. Lower elevations in fore-island areas are subject to inundation and modification by storm tides and storm surge. Sand blown from the backbeach, active dune and blowout areas, and subaerial washover areas may alter the configuration of the dunes and interdune depressions.

*Vegetation/animals.*—Fore-island and back-island dunes are well vegetated with a wide variety of grasses and flowering plants—many tolerant of salt spray. Common species include *Uniola paniculata* (sea oats), *Panicum amarum* (bitter panicum), *Ipomoea pes-caprae* (goatfoot morning glory), *Ipomoea stolonifera* (fiddle leaf morning glory), *Paspalum monostachyum* (gulfdune paspalum), and *Croton punctatus* (beach tea).

*Importance/special concerns.*—Fore-island dunes help protect other barrier-island resources and the mainland against storms by: (1) being the major line of defense against storm surge and flooding, (2) dissipating wave and current energy released by storms, and (3) providing the highest elevations on the islands. The width and height of the fore-island dune system should not be the sole basis for selection of storm-protected areas, however. Other factors such as dune continuity, orientation, vegetation, and relationship to other resource units should also be considered. Dune vegetation is particularly important because of its sand stabilizing characteristics; its destruction may severely decrease the ability of the dunes to protect against storms.

In addition to offering storm protection, fore-island dunes help trap and store windblown sand, help maintain and nourish beaches (particularly along an erosional coastline) by being a source of sediment, serve as a habitat for a unique assemblage of flora and fauna, and add to the recreational and aesthetic appeal of the barrier islands. Additional information on fore-island dunes is presented in the section entitled, "Dune Criticality."

## VEGETATED BARRIER FLATS

*General definition.*—Vegetated barrier flats are hummocky, grass-covered, sandy areas of low relief that generally lie between the fore-island dunes and bay marshes and tidal flats (figs. 2 and 6). The hummocky nature of this land reflects its origin as grass-covered, stabilized dunes, deflation flats and washover deposits. Many small vegetated barrier flats originating from sand migrating in active dune fields and/or sand deposited by storm washovers are present bayward of the main vegetated barrier flat and are surrounded by such land and water resources as wind-tidal flats, algal flats, and grassflats. Ephemeral fresh-water ponds and marshes as well as local patches of salt-marsh vegetation were mapped with this unit.

Crane Islands in Laguna Madre and two elongate islands located immediately north of the mouth of Wilson's Cut were mapped as vegetated barrier flats. These islands appear to have originated as local sand beaches and shell berms, but later became vegetated with grasses characteristic of this resource unit.

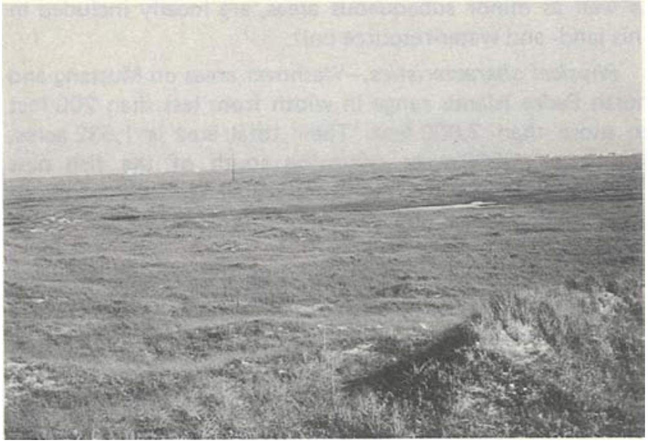


Figure 6. Vegetated barrier flat flanking fore-island dunes.

*Physical characteristics.*—Vegetated barrier flats cover a total area of 8,589 acres. This is the largest land- and water-resource unit, comprising 26.8 percent of the mapped area* (table 1). Elevations range from sea level to over 15 feet at the crest of restabilized dunes, but elevations are generally less than 10 feet and decrease toward the bay. These vegetated areas are composed primarily of fine-grained sand with scattered shell.

*Active processes.*—The vegetated barrier flat which is generally protected by fore-island dunes and stabilized by vegetation is, perhaps, the land- and water-resource unit least affected by active processes. Nevertheless, specific areas are subject to the effects of flooding (areas low in elevation), storm surge (areas not well protected by foredunes), and windblown sand (areas adjacent to unvegetated zones such as active dunes and sand blowouts, washover areas, beaches, sand flats, and subaerial spoil and made land).

*Vegetation/animals.*—Typical grasses include *Paspalum monostachyum* (gulfdune paspalum) and a variety of *Panicum* species, some of the more obvious forms include *Helinathus argophyllus* (silverleaf sunflower), and *Gaillardia pulchella* (indian blanket). These plants support a population of rodents, such as *Geomys personatus* (Texas pocket gopher), and seed-eating birds. Top carnivores include the coyote (*Canis latrans*) and raccoon (*Procyon lotor*).

Ephemeral ponds and marshes are typically vegetated with cattail (*Typha domingensis*) and common threesquare (*Scirpus americanus*) and provide habitat for birds such as the redwing blackbird (*Agelaius phoeniceus*) and pintail duck (*Anas acuta*).

*Importance/special concerns.*—Compared to other land and water resources, the vegetated barrier flat is one of the most acceptable sites for community development on the barrier island because of its extensive area, its central location with respect to other land and water resources, and its limited susceptibility to alteration by active processes.

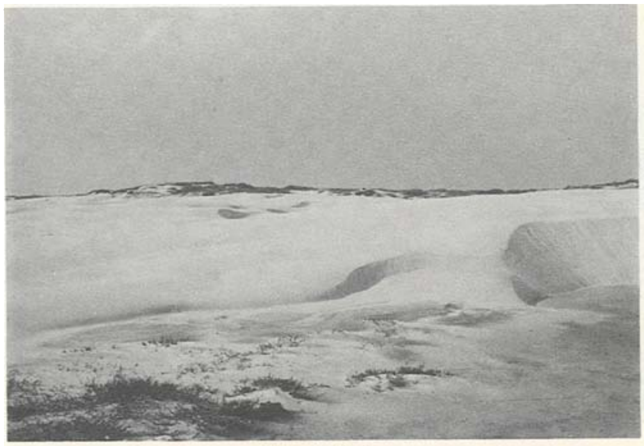


Figure 7(a)

Figure 7(b)

Figure 7. (a) Active dunes on north Padre Island; view is toward the southeast. (b) Blowout in fore-island dune area, Mustang Island; view is toward the west.

Vegetated barrier flats are also habitats for a variety of plants and animals which community developments will displace.

## ACTIVE DUNES AND SAND BLOWOUTS

*General definition.*—These areas of migrating sand dunes and sand sheets include large active back-island dune fields (fig. 7a) and associated deflation flats, as well as smaller areas of active dunes and sand blowouts (fig. 7b) in close association with vegetated fore-island and back-island dunes and washover areas. Locally, coppice mounds and wind-shadow dunes are included with these active systems. At several locations the dunes have moderately well-vegetated crests that afford relatively good stability, but their barren flanks are vulnerable to deflation. Small sand blowouts that are present along the seaward flanks of vegetated fore-island dunes were mapped with the beach, coppice mounds, and wind-shadow dunes.

*Physical characteristics.*—Of the 596 acres (table 1) covered by active dunes and sand blowouts, approximately

*The total mapped area includes the areas of all mapped land and water resources; it excludes the Gulf, Corpus Christi Bay, Corpus Christi Ship Channel, and the Intracoastal Waterway.

Figure 8. Corpus Christi Pass. Photograph taken in September of 1973 when the storm channel that sometimes connects bay and Gulf waters was closed.

548 acres occur south of the fish pass; the largest areas are located on north Padre Island. Elevations range from less than 5 feet to over 25 feet.

*Active processes.*—Active sand dunes and sand blowouts that are present adjacent to washover areas and Gulf beaches are highly susceptible to erosion and modification by winds, storm tides, and storm surge. Back-island dune fields are affected primarily by wind action, but lower elevations may be inundated and scoured by storm tides.

*Vegetation/animals.*—These active areas generally are barren, although they are locally vegetated by plants that can adapt to the unstable conditions. Early colonizing plants are important in the eventual stabilization of the shifting sand. For a discussion on plant succession and stabilization of dunes along the Texas Coastal Zone, see Dahl and others (1974).

*Importance/special concerns.*—Active dunes and sand blowouts are commonly natural features. The sand migrates bayward and, if not stabilized, may eventually be blown into the bays or into biologically productive areas such as grassflats. In addition, blowouts in the fore-island dune system are areas of weakness during storms. Active dunes that become stabilized by vegetation help to build up the barrier islands. Much of the area mapped as vegetated fore-island dunes is composed of restabilized blowout dunes. It is particularly important to protect incipient vegetation on active dune and in blowout areas to allow upbuilding and restabilization to occur.

## WASHOVER AREAS

*General definition.*—These low-lying areas are periodically inundated and subjected to intense wave and current energy during hurricanes. The largest washover areas, Corpus Christi Pass (fig. 8), Newport Pass, and Packery Channel, extend into Laguna Madre. Several smaller washovers are present north of Corpus Christi Pass; the largest of these is near the fish pass which was constructed in an existing washover area. Active dunes and coppice mounds, as well as minor subaqueous areas, are locally included in this land- and water-resource unit.

*Physical characteristics.*—Washover areas on Mustang and north Padre Islands range in width from less than 200 feet to more than 2,000 feet. Their total area is 1,532 acres, with over 1,500 acres occurring south of the fish pass (table 1). Elevations range from below sea level to about 5 feet. These areas are generally composed of sand with scattered shell.

*Active processes.*—Washover areas are zones of high physical energy during storms. Intense wave and current activity concentrated in washovers during storms scour channels and transport sediments bayward. Between storms, sand transported along the shore eventually closes the channels, and often forms ponds. Large, subaerial, unvegetated washover areas are subject to extensive modifications by windblown sand.

*Vegetation/animals.*—Major washover areas mapped in the vicinity of Corpus Christi Pass, Newport Pass, and Packery Channel are generally barren of vegetation. Extant vegetated zones adjacent to these areas were mapped according to the type of vegetation, for example, salt marsh, vegetated barrier flat, or grassflat, although these areas are also subject to the effects of storm washover. Smaller washover channels north of Corpus Christi Pass extend bayward across the vegetated barrier flats and locally are occupied with extensive marsh vegetation. The washover areas biologically resemble the wind-tidal and shallow subaqueous flats; the shallow water supports a variety of fish, shrimp, and fish-eating birds such as the spectacular great blue heron (*Ardea herodias*). The ponded channels present in the washover areas are popular fishing spots; wade fishermen typically catch spotted seatrout (*Cynoscion nebulosus*) and pinfish (*Lagodon rhomboides*).

*Importance/special concerns.*—Washover areas may have some value as energy-release ducts for storm tides and surge or as pathways through which nutrients and sediments can be flushed to enhance biologic productivity in the bays, grassflats, and marshes. Sediment transported through these areas and deposited on grassflats also can lead to reduced productivity locally. However, the primary purpose of identifying washovers on the land- and water-resources map is to delineate these hazardous areas that are the first to be flooded and subjected to high current velocities during storms. These areas should be avoided in community development.

## WIND-TIDAL, TIDAL, AND SHALLOW SUBAQUEOUS FLATS

*General definition.*—Wind-tidal flats (fig. 9a) are bay-margin environments that are inundated periodically by wind and storm tides; tidal flats are subject to daily inundation by astronomical tides; and shallow subaqueous flats are either continuously inundated or exposed only during extremely low tides. These areas have certain common characteristics. They are (1) generally located on the bay side of the barrier islands, (2) relatively flat with little or no standing vegetation, and (3) subject to flooding. Blue-green algae may flourish on wind-tidal flats shortly

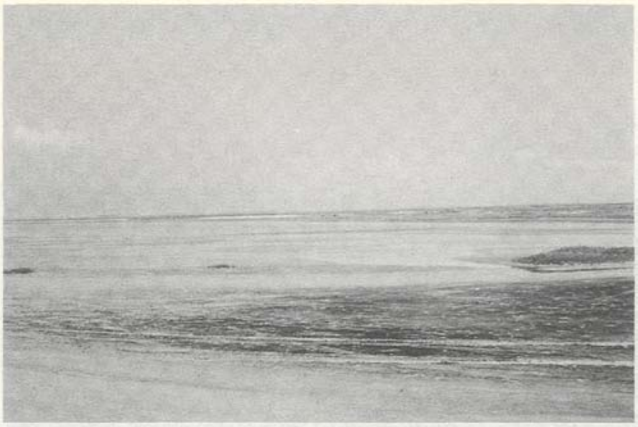


*Figure 9(a)*

*Figure 9(b)*

Figure 9. (a) Wind-tidal flat along bay margin of Mustang Island. (b) Algal flat on Mustang Island. Back island dunes are visible in background.

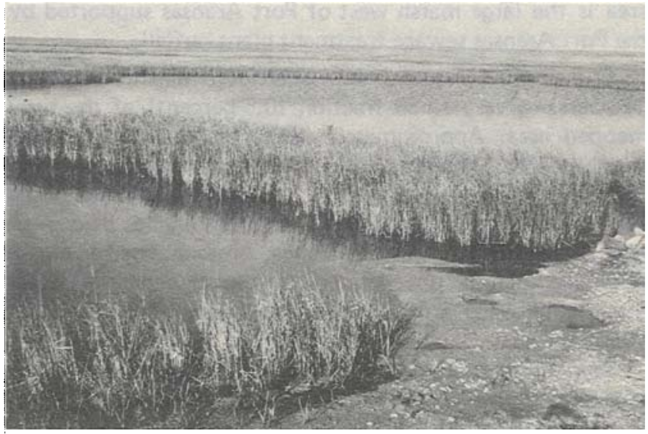


Figure 10. *Spartina alterniflora* marsh.

after inundation, producing mats which bind the sandy sediment into a tough substrate (fig. 9b).

*Physical characteristics.*—Elevations in these areas generally range from 3 feet above mean sea level on wind-tidal flats to about 3 feet below mean sea level on shallow subaqueous flats. The total area covered by this land and water resource is 4,807 acres. Most of the tidal flats are composed of sand, although a thin veneer of mud may be present in depressed areas. Some of the flats on which algal mats are present have a characteristic spongecake texture.

*Active processes.*—As noted in the general definition, these areas are flooded. When they are adjacent to washover channels and major navigation canals (such as Corpus Christi Ship Channel) they are subject to modification by strong currents that accompany storm surge and tides. Some of the higher wind-tidal flats may be flooded only a few times a year when favorable astronomical and meteorological conditions accompany strong north winds or persistent southeasterly winds. Infrequently inundated flats composed of loose sand may be modified by wind action.

*Vegetation/animals.*—In a few areas mapped as wind-tidal flats, salt-marsh vegetation such as shoregrass (*Monanthochloe littoralis*), glassworts (*Salicornia* spp.), and saltwort (*Batis maritima*) can be found. When flooded, shallow waters support a substantial population of small fish, such as the sheepshead minnow (*Cyprinodon variegatus*) and penaeid shrimp which feed on algae and detritus. They are in turn fed on by birds such as the great blue heron (*Ardea herodias*) and reddish egret (*Dichromanassa rufescens*) and, in deeper waters, by larger sport fish. Fiddler crabs (*Uca panacea*) inhabit the borders between algal flats and salt marsh, feeding on algae and detritus.

In a few areas, flats may be inundated for extended periods, during which time patches of shoalgrass and brown algae may become temporarily established. On one occasion in late 1974, shoalgrass and a type of macroalgae were observed on flats near Wilson's Cut growing in water that was two to three feet deep, but during a subsequent period of extremely low tides, these flats were subaerially exposed and only a few shoalgrass root systems could be located.

*Importance/special concerns.*—In addition to their biologic role, bayward-sloping wind-tidal and tidal flats can be thought of as flood basins which buffer or dampen wind-driven bay and lagoon waters, thereby helping to protect adjacent vegetated areas. A proliferation of navigational channels, marinas, and associated spoil on wind-tidal flats and subaqueous flats can lead to compartmentalization of these flood basins and can alter natural water-circulation patterns. In addition, some channels may act as surge conduits that may increase the extent of flooding and erosion of adjacent environments during hurricanes.

## SALT MARSHES—*SPARTINA ALTERNIFLORA* DOMINANT

*General definition.*—Marshes with high biologic productivity, composed predominantly of the salt-marsh grass *Spartina alterniflora* (fig. 10), are present in shallow bay waters north of Wilson's Cut. Unlike the extensive stands of *Spartina*, which characterize marshes on the east coast of the United States and some areas of the Texas coast, marshes along Mustang Island consist of relatively narrow, discontinuous stands of *Spartina* that fringe spoil islands and tidal flats. The fringe of *Spartina* may be transitional with marine grassflats. A major exception in the mapped area is the large marsh west of Port Aransas supported by the Port Aransas sewage-treatment plant outfall.

*Physical characteristics.*—*Spartina* marshes occupy 178 acres—a very small fraction (0.5 percent) of the total mapped area. Approximately 100 acres of marsh are located east of Shamrock Cove. Marsh plants grow in areas that range in elevation from a few inches above mean sea level (maximum about 1 foot), to a few inches below—an area defined by normal tidal range. Areas mapped as marsh generally include unvegetated peripheral zones of water that lie between and immediately adjacent to the plant communities.

*Active processes.*—Marshes occupy areas of relatively low physical energy—areas that are protected from large waves and strong currents by adjacent grassflats, tidal flats, shallow subaqueous sand flats and shoals, and natural and man-made islands. The firmly rooted plants dampen currents that accompany periods of inundation and thus help trap sediment and inhibit erosion.

*Vegetation/animals.*—*Spartina alterniflora* generally occurs in nearly monospecific stands; however, in some areas it occurs with small amounts of other salt-marsh plants such as saltwort (*Batis maritima*) and black mangrove (*Avicennia germinans*). Very little *Spartina* is eaten directly by herbivores; instead the dead grass decomposes to small detritus particles which are important in the overall food web of the bay system. Fish, crabs, and shrimp live in the shallow waters of the marsh and are preyed on by wading birds and, in deeper waters, by larger sport fish.

*Importance/special concerns.*—Although *Spartina* marshes comprise only a small portion of the study area, the productivity of these marshes in terms of organic matter produced per acre per year is higher than in any other land- and water-resource unit. Furthermore, these salt marshes respond with vigorous growth to added nutrients, removing excess nutrients which could cause disturbances in other parts of the bay system. The marsh at the Port Aransas sewage-treatment plant is an example. It has been suggested that these marshes can act as natural tertiary sewage-treatment plants if they are not overloaded.

## SALT MARSHES—*SPARTINA ALTERNIFLORA* SPARSE OR ABSENT

*General definition.*—These marshes (fig. 11) consist primarily of salt-marsh plants other than *Spartina alterniflora.* Typical plants include *Monanthochloe littoralis* (shoregrass), *Distichlis spicata* (salt grass), *Batis maritima* (saltwort), *Salicornia* spp. (glasswort), and *Borrichia frutescens* (sea oxeye). Marsh plants in this map unit generally occur slightly higher with respect to mean sea level than *Spartina alterniflora,* although some overlapping with higher zones of *Spartina* is common in *Batis* and *Salicornia* plant communities.

Marshes defined by this land- and water-resource unit occupy two rather distinct environmental settings on the bay side of the islands: (1) large areas in and adjacent to washover channels, wind-tidal flats, and vegetated barrier flats and (2) smaller areas in relatively close contact with subaqueous environments such as grassflats and bay margins.

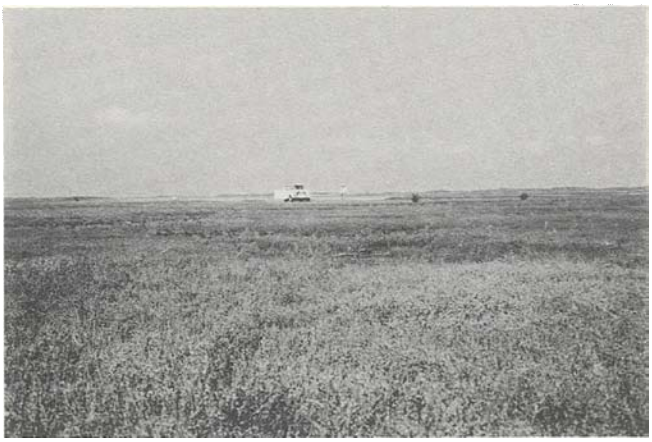


Figure 11. Salt marsh composed primarily of shoregrass (*Monanthochloe littoralis*), Mustang Island.

Most of the marshes, typifying the latter category, occupy areas on or near Shamrock Island. Many of the linear marsh features originated from the accretion of local sand beaches and shell berms. Accretionary berms on the portion of Shamrock Island west of Shamrock Cove have produced a ridge and swale topography where ridges oriented northeast-southwest along the eastern extension of the island arc around to a north-south orientation toward the western reaches of the island. Roads run parallel to and on top of the ridges. Along these elevated areas, much of the vegetation is characteristic of vegetated barrier flats; however, several varieties of plants such as salt cedar, oleander, and other shrubs and tropical plants were artificially introduced in the early 1900's (Writer's Round Table, 1950). These types of vegetation are present in relatively narrow zones along the crests of the relict beach and berm ridges. The entire vegetated area on Shamrock Island was mapped as a salt-marsh environment because of the predominance of salt-marsh plants and because of cartographic limitations.

*Physical characteristics.*—Salt marshes occupy 1,812 acres—much of which lies between the vegetated barrier flats and wind-tidal flats. The largest single marsh area, 506 acres, is located between the fish pass and Corpus Christi Pass. Elevations range from sea level to approximately 5 feet but are generally near sea level. The sediment in these marshes is predominantly fine-grained sand except in areas underlain by local sand beaches and shell berms. Here the sediment is much coarser because of large quantities of shell material.

*Active processes.*—Marshes occurring in and adjacent to washover areas are likely to be affected by storm tides, waves, and currents. Marshes in more protected areas are subject to inundation either frequently (those areas in close communication with subaqueous environments) or infrequently (those areas near vegetated barrier flats far removed—several hundred feet from subaqueous environments). Where marshes are present northwest of and adjacent to active dunes and sand blowouts, they are subject to alteration by windblown sand.


Figure 12. Subaqueous shoalgrass (*Halodule wrightii*) along the bay side of Mustang Island in the vicinity of Coyote Island (pl. 1).

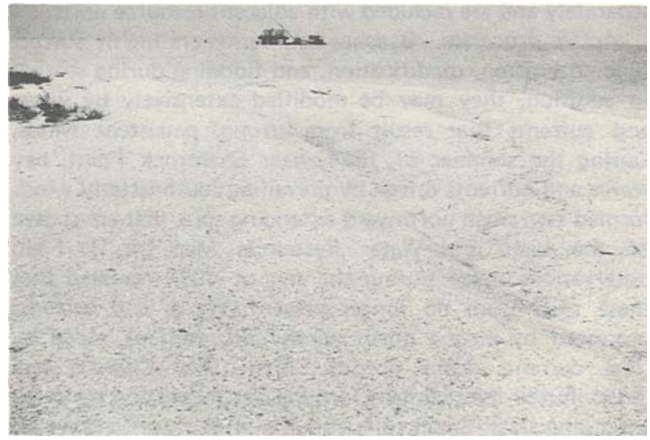


Figure 13. Shell berms along the western edge of Shamrock Island.

*Vegetation/animals.*—See the general definition paragraphs.

*Importance/special concerns.*—Many of the important food chains in the bay system are supported by organic detritus which is derived mainly from marshes, grassflats, and stream discharge. When these marshes are flooded because of tides or rainfall, they export organic detritus to the bay; however, the amount exported per acre is much less than that from *Spartina alterniflora* marsh because of lower overall production and less frequent inundation.

## GRASSFLATS

*General definition.*—Grassflats are shallow subaqueous flats containing moderate to dense growths of marine grasses which provide a highly productive biological environment (fig. 12). Locally, shallow subaqueous flats containing only sparse stands of grasses are included on the Land and Water Resources Map with adjacent, more densely vegetated grassflats.

*Physical characteristics.*—Grassflats cover 6,034 acres, which is 18.8 percent of the total mapped area. The most extensive areas occur along the margin of Corpus Christi Bay between Wilson's Cut and the East Flats and in Laguna Madre. These grassflats are a large fraction of the total grassflats in the Corpus Christi Bay system. The grasses grow in water generally less than 6 feet deep. Substrates are composed of sands and muddy sands.

*Active processes.*—Marine grasses generally grow in environments which are protected to some extent from wave energy. The vegetation tends to trap suspended sediments, which alters the original sandy sediments. Currents and waves resulting from strong and persistent winds, however, occasionally stir up the flats, resulting in considerable exportation of plant debris that accumulates along the bay margin. During a period of strong, persistent north winds, substantial amounts of plant material derived from *Halodule* grassflats east of Shamrock Cove were observed along the northern margins of lee-bordering salt marshes and vegetated barrier flats.

*Vegetation/animals.*—The most common grass is shoalgrass (*Halodule wrightii*, previously known as *Diplanthera wrightii*); some turtlegrass (*Thallasia testudinum*) is present in deeper areas. Macroalgae are present in significant quantities, such as the red alga *Graciolaria folifera*, and the epiphytic algae which grow on the grass blades contribute significantly to productivity. Grasses tend to become dormant in the late fall and winter; the regrowth in the spring coincides with the increase of fish populations.

*Importance/special concerns.*—Most of the important sport and commercial fish inhabit the grassflats as juveniles and adults, and large numbers of ducks feed in grassflats during the fall, winter, and early spring. A study in the Laguna Madre showed that an acre of grassflat produces about 137 pounds of fish per year (Hellier, 1962), mainly mullet (*Mugil cephalus*), spotted seatrout (*Cynoscion nebulosus*), and black drum (*Pogonias cromis*).

Grassflats also export large amounts of organic detritus to other parts of the bay system. They are one of the critical environments in the Coastal Zone and should be protected and managed wisely.

## LOCAL SAND BEACHES AND SHELL BERMS

*General definition.*—Beaches and shell berms (fig. 13) are present on Mustang Island along the margins of Corpus Christi Bay. The bay-margin beaches are somewhat similar to those along the Gulf, but are thinner, lower energy features, and contain much greater shell concentrations. During storms, coarse shell debris is transported above normal water levels forming storm berms or aprons.

Sand beaches and shell berms are prominent features along Shamrock Island. The island is a spit comprised of many accretionary beaches and berms that give rise to ridge-and-swale topography. Older beaches and berms have become vegetated and stabilized, and are, therefore, mapped according to the dominant type of vegetation.

*Physical characteristics.*—Local sand beaches and shell berms occupy 54 acres or 0.2 percent of the total area. The width of these unvegetated areas varies from a maximum of 500 feet (at Shamrock Point) to less than 10 feet. At many locations the beaches and berms are too narrow to map separately and are included with adjacent resource units.

*Active processes.*—Beaches and berms are highly susceptible to erosion, modification, and flooding during storms. In addition, they may be modified extensively by waves and currents that result from strong, persistent winds. During the summer of 1974, near Shamrock Point, bay waves and currents driven by prevailing southeasterly winds formed two small northward extending spits that are shown on the Land and Water Resources Map (pl. 1). Field observations made during the fall of 1974 revealed that these spits were no longer present. Waves and currents produced by strong north winds and, perhaps, aided by tidal currents from Corpus Christi Ship Channel had redistributed the sediment forming southward and eastward extending spits. Small spits and miniature ridges and swales were observed along many of the beaches reflecting the significance of littoral drift in these areas.

*Vegetation/animals.*—Black skimmers (*Rynchops nigra*) and snowy plovers (*Charadrius alexandrinus*) nest on these beaches by scooping a shallow depression in the sand. Many of the shore birds found on the Gulf beaches also feed here.

*Importance/special concerns.*—Local sand beaches and shell berms help buffer and dissipate bay wave and current energy, provide important environments for birds, and have some recreational potential. In addition, these areas are potential sources of sand and shell for local construction purposes. Excavation and removal of excessive amounts of material will probably upset natural sediment dispersal and wave and current energy dissipation processes, and, hence, lead to erosion of bay shorelines. The major purpose of mapping beaches and berms is to display unvegetated areas that are subject to flooding and rather rapid, extensive modification by wind- and storm-driven bay waters.

## BAY-MARGIN SAND AND SHOALS

*General definition.*—Shallow subaqueous sands that are subject to considerable erosion, transportation, and redeposition are present along the margins of Corpus Christi Bay (fig. 14). These highly mobile shoals and bars are located primarily in areas that are subjected to relatively intense wave and current activity often attendant with the passage of cold fronts. Much of the sediment in these sandy deposits is derived from erosion of washover fans, tidal deltas, ancient and recent substrates exposed along the bay margin, and spoil deposits. These relatively high-energy zones in which winnowing and sorting of sediments are important processes, are similar in some respects to the upper shoreface on the Gulf side of the barrier island; as on the shoreface, offshore sand bars are common.

*Physical characteristics.*—Bay-margin sand and shoals (871 acres) account for 2.7 percent of the total land- and water-resource area. The width of this unit ranges from more than 1,500 feet (south of the fish pass) to less than 50 feet (east of Shamrock Island). Water depths vary, but the maximum is generally less than 6 feet below mean sea level. Locally, shallow sand shoals appear above sea level at low tide.

Near the fish pass, more than 10 subparallel offshore

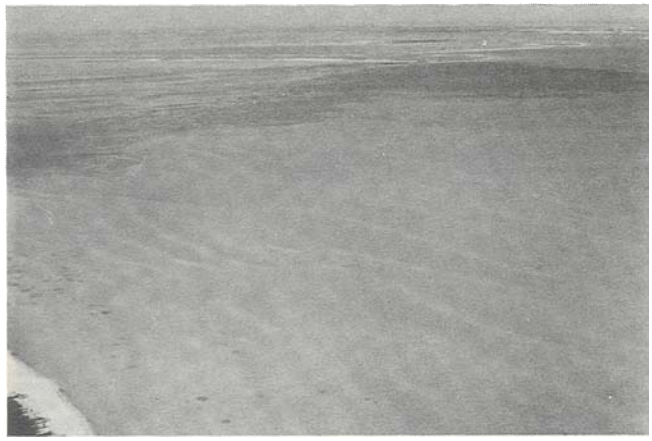


Figure 14. Bay margin sand and shoals along Mustang Island. The light colored lines are subaqueous sand bars.

sandbars are present. In bayward areas, the sandbars are relatively straight and continuous and generally parallel to the present bay shoreline. Nearer the shoreline, the pattern of bar orientation becomes more irregular and discontinuous, with bars arranged en echelon. This irregular pattern is common in areas leading into tidal flats and dredged channels. Bar heights range from about 0.5 feet to perhaps 1.5 feet (estimated), and the distance between bar crests varies from less than 25 feet to as much as 100 feet.

*Active processes.*—Bay-margin sand and shoals reflect an environment in which relatively intense wave and current energy induces considerable movement of sand, both back and forth (perpendicular to the shoreline) and along shore. Transportation and redistribution of sediment is especially important in areas unprotected from onshore waves that are generated by north winds blowing over broad reaches of Corpus Christi Bay. Wave refraction along shore is an important part of the sediment redistribution process.

*Vegetation/animals.*—Productivity in this environment is from phytoplankton, but there are local patches of shoalgrass (*Halodule wrightii*) or turtlegrass (*Thallasia testudinum*). A large variety of animals use this environment, including the blue crab (*Callinectes sapidus*), penaeid shrimp, the lightning whelk (*Busycon contrarium*), spotted seatrout (*Cynoscion nebulosus*), and other sport fish. Wading birds such as the great blue heron (*Ardea herodias*) feed on fish and shrimp in the shallower parts of the bay margin sands.

*Importance/special concerns.*—The bayward-sloping surface of the marginal sands helps to dissipate wave and current energy which, in turn, lessens undercutting and erosion of the bay shoreline. Man's activities may offset the natural equilibrium that exists in these areas. Along portions of Mustang Island, channels dredged through the bay margin sand and shoals have apparently decreased the capability of the shoals to dissipate wave and current energy and have accelerated bay-shoreline erosion.

Man's activities are, in turn, affected by the natural processes that are active in these areas. Extensive dredging and spoil-disposal activities conducted in bay-margin sand and shoal areas along the western side of Shamrock Island are very distinct in 1956 photographs. Photographs taken in

1958 indicate that the dredged channels had been partially filled, and disposed spoil was redistributed and could not be easily defined. Hardly any trace of the channels and disposed spoil can be discerned in 1969 photographs, indicating that natural active processes have been successful in restoring predredging conditions.

## SUBAERIAL SPOIL AND MADE LAND

*General definition.*—Subaerial environments that have either been created or significantly altered by man's activities are present at many locations in the Mustang and north Padre Islands area. Subaerial spoil is generally composed of sand, shell, and some clay; composition varies depending on parent material. During canal and channel dredging operations the spoil is piled on land or in subaqueous environments forming subaerial mounds (fig. 15a). The term "made land" refers to those areas that have been filled and graded or otherwise altered from a natural state for development and industrial purposes (fig. 15b). Much of the made land, of course, is composed of spoil. Vegetated and unvegetated areas are included in this unit.

Subaerial spoil deposits that have been partially reworked and redistributed by natural processes were mapped as spoil except in areas where blue-green algal mats were abundant (mapped as algal flats) or marsh vegetation was present (mapped as salt marsh). Along Corpus Christi Ship Channel, where spoil has been significantly reworked and the sediments dispersed into adjacent areas such as wind-tidal flats, the boundary separating the two environments (spoil and wind-tidal flats, for example) is more or less arbitrary, but was generally drawn with reference to changes in slope as indicated by photographic tone. In addition, sequential aerial photographs were studied to supplement identification of spoil boundaries.

*Physical characteristics.*—Subaerial spoil and made land cover 3,760 acres and comprise 11.7 percent of the total area; it is the third largest resource unit, with only vegetated barrier flats and grassflats surpassing it in areal extent (table 1).

Spoil placed along the margins of dredged channels commonly forms circular and elongate islands in subaqueous environments and ridges and mounds on land environments. At some locations, spoil deposits have elevations in excess of 15 feet above mean sea level. Spoil used as fill material for development purposes is generally graded and leveled at some specified elevation.

*Active processes.*—The degree to which subaerial spoil and made land are affected by active processes partly depends on vegetative cover, composition, location with respect to other environments, and elevation. Unvegetated spoil and made land composed of fine-grained sand are easily eroded by wind. Spoil placed along dredged canals, in washover areas, along bay margins, and in subaqueous environments is subject to extensive erosion and redistribution by waves and currents, especially during storms. Spoil disposed along the margins of a navigational channel dredged through the East Flats underwent considerable transportation and redeposition into adjacent environments during Hurricane Celia.

*Figure 15(a)*

*Figure 15(b)*

Figure 15. (a) Subaerial vegetated spoil parallels navigation channel dredged on north Mustang Island. (b) Made land along channel dredged for recreational community development on north Padre Island.

Immediately southwest of the fish pass and Park Road 53, substantial quantities of fine sand are transported from disposed spoil by strong, dry north winds and deposited in the bordering vegetation. The winnowing of the fine material from the spoil left a pavement of shell fragments.

*Vegetation/animals.*—Spoil banks show tremendous variation in plant variety and density depending on the age and elevation of the spoil. Near the water's edge, the vegetation is composed of salt marsh plants, whereas at higher elevations the spoil may be covered by plants that inhabit the vegetated barrier flats. Spoil banks frequently are significant as bird nesting areas; the types of birds present depend on the vegetation and relative amount of isolation from predators and humans. Several spoil islands in the Corpus Christi Bay area are leased by the National Audubon Society as sanctuaries for birds such as the brown pelican (*Pelecanus occidentalis*), an endangered species.

*Importance/special concerns.*—Spoil composed of sand and shell is commonly placed on suitable land environments and stabilized to guard against redistribution by active processes. Such activities can provide valuable elevated land for development purposes. In addition, well-planned and controlled alterations of noncritical environments can provide important recreational land and protect wildlife. Delineation of spoil and made land helps to illustrate the extent to which man has changed the natural environment.

Spoil disposed along the Intracoastal Waterway and the Corpus Christi Ship Channel accounts for approximately 705 acres and 1,025 acres, respectively. On north Padre Island, made land and spoil resulting primarily from recreational community development (including a golf course) occupy about 1,390 acres. Recreational community development, industrial development (petroleum exploration), and dredging of the fish pass on Mustang Island have produced areas of made land and spoil equivalent to about 640 acres. It should be noted that most of the Port Aransas area was mapped according to natural environments—vegetated barrier flats and fore-island dunes—although the land has been changed to varying degrees by community development. This area was treated differently from north Padre Island and other parts of Mustang Island where vast areas have been changed in preparation for recreational-community development; these areas were mapped as made land. Figure C-1 (appendix C) displays developed areas of Port Aransas where the natural environment has been altered and which may be classified as made land.

Because of continuing recreational-community development since June, 1974, the total area of spoil and made land has increased. For example, at one development located approximately 2.5 miles southwest of the corporate boundary of Port Aransas, two separate areas of spoil (pl. 1) are presently joined because of continued dredging and spoil disposal. Similar operations have increased the areal extent of spoil and made land on north Padre Island.

The high salinity of material dredged from bay environments generally inhibits the growth of vegetation until the sediment has been adequately flushed by fresh water. Special measures may be required to stabilize loose, fine-grained material until it can establish and maintain vegetation. Developers on north Padre Island have had some success in stabilizing barren made land and subaerial spoil by using native hay, cut and baled from nearby vegetated barrier flats. The grasses are baled after seeds have been produced but before they have been released from the parent plant. The plant material is spread over the construction site where it absorbs moisture and forms a relatively dense mat that helps stabilize loose sand until the native seeds sprout. This method has apparently been effective in controlling sand movement at windspeeds of up to 50 mph (Padre Isles Development Corporation, personal communications).

## SUBAQUEOUS SPOIL

*General definition.*—In many areas, spoil occurs in subaqueous environments either as a result of initial disposal operations or as a result of natural dispersal by erosion/transportation processes or both (fig. 16). Most subaqueous spoil in the Mustang and north Padre Islands area fringes subaerial spoil that parallels dredged channels.

Figure 16. Subaqueous spoil along the margin of unvegetated subaerial spoil south of the Corpus Christi Ship Channel. View is toward the east.

In areas where subaqueous spoil has undergone considerable redistribution and dispersion into adjacent environments, such as subaqueous sand flats and bay-margin sand and shoals, defining boundaries were drawn with reference to: (1) the original site of disposal as indicated by sequential photographs, (2) the extent of redistribution and dispersal as determined by photographic tone, and (3) the nature of adjacent environments. At some locations, such as north of Wilson's Cut, marine grasses (*Halodule*) have become established on subaqueous spoil. These areas were mapped as grassflats. Information on the extent to which spoil areas have been reclaimed by marine grasses is presented in the section on historical monitoring.

*Physical characteristics.*—Subaqueous spoil occupies approximately 890 acres in the Mustang and north Padre Islands area; it comprises 2.8 percent of the total area of land and water resources. The most extensive occurrences are along the Intracoastal Waterway (396 acres), Corpus Christi Channel (216 acres), and in the Shamrock Island - Wilson Cut area (109 acres). Like subaerial spoil and made land, the composition of subaqueous spoil is variable—generally consisting of sand, silt, shell, and clay.

*Active processes.*—Subaqueous spoil is susceptible to extensive reworking by waves and currents that tend to concentrate coarse material while spreading finer sediments into adjacent, low-energy subaqueous environments. Coarse material concentrated along bay margins may eventually be tossed above sea level by storm waves forming local shell berms and beaches.

*Vegetation/animals.*—Biologically, subaqueous spoil is very similar to "bay-margin sand and shoals" with productivity mostly from phytoplankton and sparse marine seagrasses; these areas are used by a wide variety of animals.

*Importance/special concerns.*—Although disposal of spoil in subaqueous environments is not recommended because of possible compartmentalization of natural environments, restriction of natural water circulation patterns, and disturbance of biologically productive areas, use of existing areas of subaqueous spoil for developmental purposes is often preferable to filling adjacent environments.

Figure 17(a)

Figure 17(b)

Figure 17. (a) Fish pass (Water Exchange Pass), Mustang Island. View is bayward. (b) Navigation channels in a recreational community development on Mustang Island.

## NAVIGATION CHANNELS AND PERMANENT SURFACE WATER BODIES

*General definition.*—In many areas of north Padre and Mustang Islands, canals and channels have been dredged for recreational, commercial, industrial, and biological purposes (fig. 17a and b). These channels are generally narrow with relatively straight boundaries. Of the natural water bodies present, only those considered permanent are shown on the Land and Water Resources Map (pl. 1), although many ephemeral fresh-water ponds exist on the vegetated barrier flats and in interdune depressions.

*Physical characteristics.*—Navigation channels and permanent surface-water bodies cover approximately 816 acres, which is 2.5 percent of the total mapped area. This area does not include the Gulf, Corpus Christi Bay, Intracoastal Waterway or Corpus Christi Channel. Of the 816 acres, recreational-community development in the north Padre Island area accounts for 340 acres, oil and gas exploration and development near Shamrock Island and on Mustang Island are responsible for approximately 230 acres, and recreational-community development on north Mustang Island, including marinas at Port Aransas, accounts for 160 acres. The remaining area of approximately 85 acres includes the fish pass and other smaller channels and water bodies.

Depths of channels vary from less than 5 feet in some recreational developments to more than 40 feet in the Corpus Christi Ship Channel. Average depths at the center of channels constructed and maintained in recreational-community developments generally range from about 7 to 12 feet. Channels vary from less than 100 to more than 400 feet wide.

*Active processes.*—Dredged channels can facilitate movement of storm waters, increasing the rate and extent of flooding and erosion of adjacent barrier island environments. Bulkheads have recently been installed along portions of the fish pass because of extensive bank erosion; erosion rates have been particularly high at the bend in the pass. A major hurricane has not made landfall in the area since the fish pass was constructed. Subaerial spoil placed along the channel dredged through East Flats (North Mustang Island) underwent considerable erosion during Hurricane Celia.

*Vegetation/animals.*—Primary biologic production in channels is mainly caused by phytoplankton, although marine grasses may become established in shallow areas (1 to 5 feet). Many fish, crabs, and shrimp found in the bays also inhabit channels. In community development channels, these include brown shrimp (*Penaeus aztecus*), blue crabs (*Callinectes sapidus*), bay anchovy (*Anchoa mitchilli*), and Atlantic croaker (*Micropogon undulatus*).

*Importance/special concerns.*—Channels which connect the bay with the Gulf of Mexico, such as the fish pass and Corpus Christi Ship Channel, serve the vital purpose of providing a pathway for migration for adult organisms which leave the bay to spawn and for juveniles which enter the bays to grow. In addition, many organisms more characteristic of the nearshore Gulf are found in these channels. Water-quality problems are not common in these channels because the channels are dynamically flushed.

Channels in developments can provide habitat for organisms if water-quality problems can be overcome. Shrimp, crabs, and fish are generally found in canals, which can provide a refuge from temperature extremes experienced in grassflats or shallow bays. Unfortunately, most development canals in Florida and Texas have experienced water-quality problems; the extent to which organisms could make use of canals with better water quality is not well known.

# ACTIVE PROCESSES AND NATURAL HAZARDS

The importance of active processes and natural hazards in the Coastal Zone cannot be overemphasized. The complex interaction of eolian processes, tropical storms and hurricanes, waves and longshore currents, tidal currents, and subsidence and sea-level rise effect relatively rapid and continuous change in the land and water resources of the barrier islands. To understand these changes better, it is helpful to focus on the active processes and natural hazards that induce them.

## EOLATION

Eolation is the work performed directly by the wind as well as indirectly by wind-driven currents and waves. These subjects have been briefly discussed under the topics of dunes and wind-tidal flats, but the following comments are included for continuity in the discussion of active processes.

### Dunes

The migration of sand dunes is common throughout the area but is more important on north Padre Island than on Mustang Island. Dune migration is probably due to a combination of several factors among which are climate and historical land use. Apparently the climatic changes from dry subhumid toward semiarid conditions between northern Mustang and Padre Islands are sufficient to cause some differences in vegetative cover or at least to create a critical situation whereby minor declines in rainfall cause significant decreases in vegetative density. Coupled with the long history of livestock (sheep and cattle) grazing on Padre Island (Price and Gunter, 1943; Sheire, 1971) and grass burning (Otteni and others, 1972), this climatic effect accounts for major differences in dune activity at the various locations.

Blowouts can be initiated not only by dune devegetation from wind erosion and drought but also by erosion from storm waves. Salt-water flooding is also detrimental to vegetation not tolerant of extensive exposure to high salinity. Some blowouts and dune fields grow by migrating across and burying back-island vegetation; at the same time, the blowout dunes are nourished by sand transported from the beach and foredune area. Other blowout-dune areas detached from the foredunes migrate as a unit with revegetation at the rear margins.

Both aerial photograph and field observations indicate that the direction of net migration of blowout dunes is west and northwest along the central Texas coast. This fact was also substantiated by Boker (1956) who attributed the direction of net dune migration to the resultant vector of southeasterly and northerly winds. Dune migration of about 75 feet per year and subsequent bay-shoreline progradation have been recorded on northern Padre Island (Hunter and Dickinson, 1970) based on movement of blowout-dune fields shown on aerial photographs in 1948 and 1967. Price (1971) reported dune-migration rates ranging from 30 to 85 feet per year on northern Padre Island.

Estimates of total sand volume stored in dunes on the barrier islands have not been made but significant vertical accretion has occurred as a result of eolian processes. Using heuristic reasoning, one infers that initial accumulation of wind-transported sand is rapid but that subsequent dune growth is less rapid. Apparently, foredunes can be eroded and rebuilt over a period of 10 to 20 years. Beach profiles, field observations, and comparison of aerial photographs attest to the rapidity of dune rebuilding. On Mustang Island, vegetated dunes 3 to 7 feet high have formed in front of the post-Carla (1961) wave-cut face of the foredune ridge. Quantitative data are lacking on the rates of sand accumulation and dune growth; there are virtually no data available covering extended periods of time. Otteni and others (1972) provide some information on sand accumulation from eolian processes. They demonstrated that dunes as high as 7 feet could be obtained in 40 months on north Padre Island (south of the area covered by this report). Total volume of sand accumulated at individual stations over 4 years (June 1969 to May 1973) ranged from 6.89 to 16.92 cubic yards per linear foot of beach. A mean value of 15.08 cubic yards per linear foot of beach was obtained from stations spaced in a 1,200-foot test section on north Padre Island. This area comprises about 18,000 cubic yards of sand that accumulated over slightly more than 2 years (May 1970 to July 1972).

Artificial methods used to trap sand on north Padre Island also provide an estimate of eolian sand transport. Volume of sand accumulated along picket fences over a 14-month period (March 1966 to May 1967) ranged from 7.0 cubic yards to 13.7 cubic yards per linear foot of beach (Gage, 1970).

It should be noted, however, that dune stabilization, while appearing to be environmentally sound, can be counterproductive and may have a definite impact on beach steepness and erosion. This counterproductivity was demonstrated on the North Carolina coast where artificially nurtured vegetated dunes resisted storm-wave attack so well that the normal exchange of stored sand between the dunes and beach was eliminated; increased beach steepness and beach erosion resulted from this stabilization effort (Dolan and Godfrey, 1973).

### Wind Tide

Although wind tides are recognized as important agents of flooding and sedimentation, few data on wind tides have been published for the Texas coast. The magnitude of wind tides is dependent on wind velocity, wind duration, water depth, and length of fetch. Laboratory experiments by Sibul and Johnson (1957) suggested that bottom roughness, as well as wind velocity, is responsible for higher water levels set up in shallow water. Smith (1974) emphasized the importance of meteorological effects on water levels in Corpus Christi Bay. He also concluded that the tides in the bay are characteristically diurnal because the semidiurnal tidal constituent is dampened by the Corpus Christi Ship Channel.

### Hurricane Winds

Wind is important in the development of hurricane surge, but the most adverse attributes of wind are the devastating force and near total destruction that normally accompany hurricanes. The destruction by hurricane wind (greater than 74 mph) can come from tremendous gusts or high sustained winds. Hurricanes are commonly accompanied by tornadoes that also cause considerable damage.

Celia (1970) is an example of a hurricane that caused more economic loss from wind damage than from flooding. Hurricane Beulah was characterized by flooding from aftermath rainfall but almost equally important were the 49 tornadoes associated with the storm.

## FLOODING

Extensive flooding of the central Texas coast is primarily associated with hurricanes, whereas minor flooding is commonly the result of abnormally high astronomical tides and/or wind tides set up by persistent strong winds.

### Salt-Water Flooding

Salt-water flooding accompanies storm surge which is the mound of water in front of and to the right of the storm track. Storm surge depends on the interaction of cyclonic wind circulation, astronomical tide, barometric pressure, direction of storm approach, and forward speed of the storm in relation to the coast. Shelf width and water depth over which the storm travels also have a bearing on development of surge heights.

Table 2. Maximum hurricane surge height greater than 5 feet. (Recorded at Port Aransas, 1919 to 1974.)

| Date | Surge Height (feet) | Reference |
|---|---|---|
| 1919 | 11.5 | Price (1956) |
| 1933 | 5.0 | Price (1956) |
| 1945 | 9.0 | Bodine (1969) |
| 1961 | 9.3 | U.S. Army Corps of Engineers (1962) |
| 1967 | 9.4 | U.S. Army Corps of Engineers (1968) |
| 1970 | 9.2 | U.S. Army Corps of Engineers (1971a) |

Rapid flooding occurs when the storm surge exhibits seichelike characteristics. Examples of the rapid rise in water level from such a storm surge were witnessed by residents of Galveston in 1900 and Corpus Christi in 1919. According to I.M. Cline, a trained observer of meteorological phenomena, water depth increased 4 feet in a few seconds during the 1900 storm in Galveston (Dunn and Miller, 1964).

Maximum storm surge recorded on the Texas coast was 22 feet which occurred in Matagorda Bay from Hurricane Carla in 1961. Gulf beach high water elevations from Carla along the central Texas coast, however, ranged from 8.9 to 9.3 feet (U.S. Army Corps Engineers, 1962). Other significant storm surges were measured at Port Aransas (table 2).

Although not quite as severe as Carla, storm surge associated with Hurricane Beulah also caused major flooding along the central Texas coast. High water elevations in the study area ranged from 6.7 to 9.4 feet. Approximately 80 percent of the area was flooded by Beulah with the exception of north Padre Island where about 70 percent of the area was inundated.

Beaches and other low-lying areas can be flooded from distant storms, as shown by Shepard and Moore (1955, p. 1,477) who photographed the flooding on north Padre Island in response to a hurricane which made landfall east of the Mississippi delta. Probably many other storms, including the hurricanes of 1916 and 1933, have caused considerable flooding of the barrier islands. At least these records (table 2) provide some estimate of the frequency and magnitude of major flooding of the central Texas coast.

Masch and others (1970) used synthetic hurricanes generated by a computer model to evaluate expected surge elevations on north Padre Island. Their model indicated that a hurricane surge of 11.7 feet centered on Port Aransas would produce a 7.9-foot surge on the bay side of Padre Island at Packery Channel. These data were designed to estimate the 1.0 percent probability or 100-year storm.

Bodine (1969) used empirical data to determine the frequency of a particular surge height during a 100-year period. The graph for surge frequency on the open coast near Port Aransas (Mustang Island) showed that a surge height of 11 feet can be expected once every century, a surge height of 9 feet should occur 3 times each century, and surge heights in excess of 4 feet should occur 20 times each century or about every 5 years. Obviously, these figures are not meant to be used for predicting actual reoccurrence but rather to relate the frequency of past events and provide an estimate of future surge height. The data clearly indicate that the central Texas coast is subject to relatively frequent flooding from hurricanes. Coastal residents are aware of the problem; however, developers and prospective home owners should be aware of the potential hazard from flooding.

### Fresh-Water Flooding

Hurricanes commonly bring fresh-water flooding from torrential rainfall. Hurricane Beulah is generally remembered as a storm characterized by fresh-water flooding even though there was considerable salt-water flooding associated with the storm. Aftermath rainfall along the central Texas coast ranged from 11 inches to 14 inches between September 19 and September 26, 1967 (U.S. Army Corps Engineers, 1968). Documentation of fresh-water flooding from other storms similar to Beulah is difficult because of the lack of sufficent data. At least one other storm in the 20th century caused noticeable fresh-water flooding. Price (1956) reported that flood water from rain remained ponded on Padre and Mustang Islands for about a week following the October 1949 hurricane.

Because of the low relief and poorly defined surface drainage in the area, rainfall at the rate of several inches per hour or total rainfall of several inches or more accumulated in a few days is sufficient to flood many areas.

## HURRICANE WASHOVER

From hurricane records covering 85 years (1886 to 1970), Simpson and Lawrence (1971) calculated the probability that a tropical cyclone will occur in any one year for 50-mile segments of the United States coast. Their data indicate that each year the central Texas coast has a 13-percent chance of being affected by some type of tropical cyclone. The chances that a hurricane will strike in any given year is 7 percent, whereas the probability that a great hurricane will occur in any given year is 4 percent.

Hurricane landfall along the central Texas coast occurred in 1934, 1936, 1970, and 1972, but other hurricanes with landfall along other parts of the coast have had more impact, notably the hurricanes of 1919, 1961 (Carla), and 1967 (Beulah).

Areas presently classified as active hurricane washover channels and fans are Packery Channel, Newport Pass, and Corpus Christi Pass. Surficial features, however, indicate that numerous washovers were active during the geologic past.

Both Andrews (1970) and Nordquist (1972) studied hurricane washovers on San Jose Island, immediately north of the study area. Nordquist concluded that the origin of North Pass was related to the migration of Aransas Pass, the drought of 1915 to 1918, and the hurricane of 1919. The southern end of San Jose Island, between Aransas Pass and North Pass, was extensively eroded during the hurricane of 1919 (Price, 1956). Nordquist estimated that 6.3 million cubic yards of sand were deposited as a progradation of the washover fan into Aransas Bay. He attributed subsequent accretion and progradation of the washover fan to the numerous hurricanes that have caused flooding in the North Pass area, notably the hurricanes in the early 1930's and 1940's. Apparently, the fan had attained its present size and configuration by 1938. Minor reworking of the margins and surface have occurred, however, more recently from storm washover, notably from hurricanes Carla, Beulah, and Celia. Frequent overwash during the 13 years since Carla has left the North Pass area vulnerable to future washover.

Distinct physiographic features such as distributary channels and eolian mounds characterize the older washover channels on the Texas coast. In addition to being relatively small in area, more recent and currently active washovers exhibit barren surfaces marked by poorly defined distributary channels.

Packery Channel, Newport Pass, and Corpus Christi Pass are not strictly classified as components of hurricane washover fans in a genetic sense, although they are certainly subject to washover and flooding from higher than normal tides. Past records indicate that these channels functioned as tidal inlets, although they were often modified by storms and their activity was intermittent. The subaerial and subaqueous sediments associated with these channels consequently represent both tidal delta and washover-fan deposits.

## WAVES AND LONGSHORE CURRENTS

Observations of breaker height and longshore current velocity on Mustang Island during the fall and winter of 1971-72 by Davis and Fox (1972) indicated that breaker height is generally less than 4 feet with mean breaker height being slightly more than 2 feet. The velocity of longshore currents ranged between zero and 3.9 feet per second, and averaged 0.38 feet per second and 0.79 feet per second during the fall and winter, respectively. Although rip currents develop along the central Texas coast during moderate- to low-energy conditions, they are subordinate coastal processes (Davis and Fox, 1972).

It is generally recognized that basin configuration and shoreline orientation plus the approach of wave trains controlled by predominant wind direction produce southwesterly littoral drift along the upper and central Texas coast, whereas littoral drift is northerly along the lower coast (Lohse, 1955). Apparently, the zone of convergence is located near 27° N. latitude (Watson, 1971), but seasonal conditions can cause the convergence to shift up the coast toward north Padre Island (Curray, 1960). Although the direction of littoral drift at any given time depends on wind direction (Watson and Behrens, 1970), the net direction of drift along the central Texas coast is southwesterly. This is documented historically by the migration of Aransas Pass and inlets in the Corpus Christi Pass - Packery Channel area. Remote sensing techniques have also been used to document the characteristics and southwestward direction of suspended sediment transport (Berryhill, 1969; Hunter, 1973).

Because of the seasonal reversals in direction of littoral transport associated with changing wind direction (Blankenship, 1953; Kimsey and Temple, 1962, 1963; Watson and Behrens, 1970; Hunter and others, 1974; Hill and others, 1975), net littoral drift along the central Texas coast is only about 10 to 20 percent of the gross littoral drift (Carothers and Innis, 1962; Behrens and Watson, 1974). Gross littoral drift in the vicinity of the Mustang Island fish pass from July 1972 to June 1973, computed by Behrens and Watson (1974), was about 1 million cubic yards; net littoral drift (southward) was from 39,250 to 85,200 cubic yards.

## TIDAL CURRENTS

Under normal conditions, the tidal prism, tidal cycle, and inlet cross-sectional area are major factors in determining tidal-current velocity. The bays of the central Texas coast are large but shallow, and because the tidal range is low (1.5 feet), the tidal prism is not great. Furthermore, river discharge into the bays is normally minor, and thus precludes the development of increased hydrostatic head. In addition, the tidal cycle is generally diurnal, thus allowing greater time for the exchange of water. Low tidal-current velocities are the cumulative effect of these factors in conjunction with the stable cross-sectional area of the inlets.

Generally ebb velocities are slightly greater than flood velocities through the major inlets such as Aransas Pass. Current-velocity measurements at Aransas Pass in 1904 (U.S. Army Corps Engineers, 1904) were 2.37 and 2.51 feet per second for flood and ebb flow, respectively. The equivalent discharge at those velocities was approximately 39,500 cubic feet per second and 41,000 cubic feet per second. Since these measurements were taken, the channel at Aransas Pass has been deepened. Caldwell (1955) listed the tidal-current velocity at Aransas Pass as 1.45 feet per second. Most of the 173 current-velocity measurements taken at Aransas Pass by Shepard and Moore (1955) were less than 2.0 feet per second.

Tidal currents through Corpus Christi Pass prior to its most recent shoaling showed stronger flood currents than ebb currents. Davis and others (1973) reported that flood velocities of about 1.8 feet per second were common, whereas maximum ebb velocity was about 0.8 feet per second. Maximum discharge measured during the same study was 1,590 cubic feet per second.

Ebb-current velocities can be significantly increased under conditions that increase the volume of water transported out of the bays. Strong north wind tends to concentrate water along the southern bay margins resulting in greater hydrostatic head and higher ebb velocities. Increases in volume of bay water can also be caused by increased river discharge from fresh-water flooding. Furthermore, storm-surge flood is followed by storm-surge ebb (Hayes, 1967) which drains the flooded bay areas. Runoff from both fresh-water and salt-water flooding contributes to increased ebb-tide velocities.

Because of the intermittent opening and closing of Corpus Christi Pass, a fish pass was dredged across Mustang Island to connect Corpus Christi Bay with the open Gulf. In the past, tidal inlets in the Corpus Christi Pass - Packery Channel area served the same function naturally. The inability of these tidal inlets to maintain tidal exchange for extended periods may be partly caused by the deepening of Aransas Pass (Collier and Hedgpeth, 1950; Price, 1952). Detailed changes and adjustments in and around the fish pass during its first year of operation have been studied by Defehr and Sorensen (1973) and by Behrens and Watson (1974). Maximum discharge recorded at the fish pass was about 4,000 cubic feet per second. Maximum tidal-current velocities averaged about 3 feet per second; however, most of the measured flow velocities were less than 2 feet per second.

## SUBSIDENCE AND RELATIVE SEA-LEVEL RISE

Two factors of major importance relevant to land-sea relationships along the central Texas coast are sea-level changes and compactional subsidence. Shepard (1960) discussed Holocene rise in sea level along the Texas coast based on carbon-14 data. During historical time, relative sea-level changes were deduced by monitoring mean sea level as determined from tide observations and developing trends based on long-term measurements (Gutenberg, 1933, 1941; Marmer, 1949, 1951, 1954; Hicks and Shofnos, 1965; Hicks, 1968, 1972). This method, however, does not distinguish between sea-level rise and land-surface subsidence. More realistically, differentiation of these processes or understanding their individual contributions, if both are operative, is an academic question; the problem is just as real no matter what the cause. Unfortunately, the tide records at Port Aransas are not of sufficient duration so that a definitive statement can be made about relative sea-level changes.

Shepard and Moore (1960) speculated that coastal subsidence is probably an ongoing process augmented by sediment compaction. More recent data tend to support the idea of land subsidence along the Texas coast (Swanson and Thurlow, 1973).

It should be noted, however, that through geologic time the central Texas coast, as a region, has been situated over a more stable and positive tectonic element, the San Marcos arch, than have the adjacent areas that occupy the Rio Grande embayment to the south and the East Texas embayment to the northeast. Furthermore, stream gradients for the Guadalupe and Nueces Rivers suggest that uplift has been greater in areas updip of the hingeline over the San Marcos arch than in adjacent areas.

Because Swanson and Thurlow (1973) were interested in the subsidence component reflected in tide-level variations, their data were intentionally adjusted so that the contribution from sea-level rise would be eliminated from their analysis. Nevertheless, tidal data gathered from numerous coastal areas indicate that sea level continues to rise at the rate of approximately 1 foot per century.

In the overall analysis, the balance between factors of tectonic stability and sea-level rise would appear to favor continued sea-level rise relative to the land surface.

# HISTORICAL CHANGES

## HISTORICAL MONITORING PROGRAM

Historical monitoring is the documentation of changes in natural boundaries and environments that occurred through recent historical time as indicated by comparison of repetitive sequential mapping using aerial photographs or other base data representing certain selected time intervals. Because natural boundaries and environments in the Coastal Zone are dynamic and continually changing, it is important that such variability be recorded and understood (1) to establish baseline data for future monitoring, (2) to permit some differentiation of natural as opposed to human-induced changes, (3) to allow reasonable prediction of future changes based on past events, and (4) to provide a factual basis for assessing environmental impact of proposed activities.

Historical monitoring implies both a concept and a technique which can be applied to a variety of natural phenomena. In this particular study, however, the technique has been restricted to natural boundaries and environments present along the central Texas coast, including Mustang and north Padre Islands.

## CHANGES IN NATURAL ENVIRONMENTS: MUSTANG AND NORTH PADRE ISLANDS (1938-1974)

Between 1938 and 1974, significant changes occurred on Mustang and north Padre Islands as a result of both natural processes and human activities. The most obvious natural changes include the establishment of vegetation on active dunes and interdune areas to form extensive areas of vegetated fore-island and back-island dunes and vegetated barrier flats. The expansion of subaqueous grassflats into areas of former wind-tidal flats and subaqueous sand shoals was also a natural change. Significant modifications of the natural environment as a result of industrial, commercial, and residential developments are particularly obvious in the Port Aransas - Harbor Island, Shamrock Island, and north Padre Island areas.

### Methodology

To evaluate changes in the natural environment, near vertical aerial photographs and mosaics flown in 1938, 1956, and 1974 were used to prepare maps showing the distribution of natural environments in 1938, 1956, and 1974 (fig. 18). (See pages 22 and 23.) The map for 1938 was prepared by tracing boundaries of each environment directly from a photomosaic (scale 1:36,000) flown in November 1938. Black-and-white photographs (scale 1:25,000) taken in January 1956 were used to produce the map environments in 1956. The Land and Water Resources Map (scale 1:24,000) was slightly modified and reduced to a scale of 1:36,000 to produce the map of environments during 1974. After the maps were prepared, each at a scale of approximately 1:36,000, the areal extent of the individual map units on each of the three maps was determined by planimeter. The descriptions of the changes in the natural environment which follow are based on a comparison of these three maps and the planimeter data derived from them.

### Environmental Map Units

The environmental units delineated on the maps for 1938, 1956, and 1974 (fig. 18) represent coastal environments that have been distinguished by characteristics such as sediment size, type and amount of vegetation cover, topographic relief, proximity to sea level, and depositional process. Most of these units are the same as (or combinations of) those units delineated on the Land and Water Resources Map (pl. 1) and described in a previous section. The areas mapped as salt marsh, however, on the map for 1974 include *Spartina alterniflora* marshes and a few marshes where *Spartina alteriflora* is absent or sparse (pl. 1). Moreover, in washover areas, additional map units were delineated because of the emphasis on washover versus eolian processes.

#### Washover areas

Segments of Mustang Island that are breached or overridden by storm tides and surges are called washover areas. The major washover area on Mustang Island (Corpus Christi Pass, Newport Pass, and Packery Channel) comprises what was previously a natural tidal inlet system that has since been modified by storm washover. Commonly the Gulf entrances of these inlets are closed by littoral drift; however, periodically they are reopened by hurricanes and other lesser storms.

Other washover areas occur both to the north and south of the area described above. At the north end of the island, older washover fans were already densely vegetated by 1938 and have been mapped as vegetated barrier flats. Major units mapped in washover areas are: (1) subaqueous sand shoals and (2) subaerial sand flats.

*Subaqueous sand shoals* include shallow subtidal and lower intertidal areas dominantly composed of sand. *Subaerial sand flats* include upper intertidal and locally vegetated supratidal areas also dominantly composed of

Table 3. Areal extent of map units for north Mustang (Aransas Pass to Wilson's Cut), south Mustang (Wilson's Cut to Corpus Christi Pass), and north Padre Islands for the years 1938, 1956, and 1974 (Nueces County, fig. 6). (All values are given in square miles. Area determined by planimeter.)

| | 1938 | | | | 1956 | | | | 1974 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North Mustang | South Mustang | North Padre | Total | North Mustang | South Mustang | North Padre | Total | North Mustang | South Mustang | North Padre | Total |
| Beach | 0.90 | 0.70 | 0.52 | 2.12 | 1.00 | 0.78 | 0.55 | 2.33 | 0.55 | 0.34 | 0.35 | 1.24 |
| Vegetated dune/barrier flat | 6.15 | 2.88 | 2.03 | 11.06 | 8.23 | 6.13 | 3.24 | 17.60 | 7.46 | 8.11 | 5.25 | 20.82 |
| Active dunes | 1.78 | 5.58 | 3.16 | 10.52 | 0.10 | 4.07 | 2.18 | 6.35 | 0.03 | 0.03 | 0.90 | 0.96 |
| Washover areas | | | | | | | | | | | | |
| Subaqueous sand[a] | 0 | 2.14 | 3.35 | 5.49 | 0 | 2.43 | 4.47 | 6.90 | 0 | 0.76 | 4.40 | 5.16 |
| Subareal sand[a] | 0 | 1.38 | 1.85 | 3.23 | 0 | 0.54 | 1.78 | 2.32 | 0 | 0.17 | 0.74 | 0.91 |
| Wind-tidal and tidal flats | 7.50 | 1.71 | 0 | 9.21 | 6.64 | 0.08 | 0 | 6.72 | 3.85 | 1.86 | 0.12 | 5.83 |
| Salt marsh | | | | X[c] | | | | X | | | | 0.27 |
| Grassflats | 3.37 | 0.57 | 0[b] | 3.94 | 1.73 | 0.83 | 1.41 | 3.97 | 4.80 | 2.90 | 2.76 | 10.46 |
| Sand beaches and shell berm | 0.34 | 0.08 | 0 | 0.42 | 0.43 | 0.04 | 0 | 0.47 | 0.24 | 0.08 | 0 | 0.32 |
| Bay margin sand and shoal | 0.50 | 0.84 | 0 | 1.34 | 0.61 | 1.08 | 0 | 1.69 | 0.53 | 0.99 | 0 | 1.52 |
| Spoil, made land, and canals | 2.02 | 0.39 | 0 | 2.41 | 3.98 | 0.91 | 1.63 | 6.52 | 3.17 | 1.54 | 3.19 | 7.9 |
| Total area of units | 22.56 | 16.27 | 10.91 | 49.74 | 22.73 | 16.89 | 15.26 | 54.87 | 20.63 | 16.78 | 17.71 | 55.12 |

[a]Includes sands of washover, tidal delta, and/or eolian origin.

[b]Some grassflat areas may have existed in Laguna Madre, quality of photographs did not permit mapping.

[c]Extremely small but unmappable areas of salt marsh.

sand. In both the subaqueous and the subaerial areas, deposits of dominantly washover and/or *tidal* origin are distinguished from those interpreted to be dominantly of washover and/or *eolian* origin. The bayward accretion of Mustang Island can be attributed primarily to washover processes; eolian and tidal processes are of secondary importance. Locally, subaqueous sands of washover and/or eolian origin on the bay side of the island have been reworked by waves and currents to produce subaerial sand flats.

### Distribution of Genetically Related Surface Units

The relative geographic distribution of the map units is largely predictable (fig. 2) because the map units are genetically related by long-term ongoing processes. However, individual map units are not necessarily uniformly distributed throughout the study area (table 3). For example, between 1938 and 1974, active dunes and washover areas were concentrated on southern Mustang and northern Padre Islands, whereas wind-tidal flats were more widespread on northern Mustang Island. Moreover, the areal extent of individual map units (table 3) may change significantly as a result of ongoing processes related to tropical cyclones, climatic variations such as droughts, and, in some instances, human activities. Changes in the areal extent of the individual map units with time are significant because each surface unit has unique characteristics which determine its capability for use. Thus, as the areal extent of individual map units changes with time, the resource capability of those geographic areas also changes.

The areal extent of the individual map units for 1938, 1956, and 1974 are tabulated in table 3. Except for the (1) sand beaches and shell berms and the (2) bay margin sands and shoals, which together comprise 4 percent of the area, the areal extent of the map units changed significantly between 1938 and 1974 (fig. 19). The data reflect both changes in the relative importance of natural processes and the intensity of human activity. For example, the change in the importance of eolian processes in the study area is demonstrated by the fact that in 1938, 19 percent of the total area was occupied by eolian landforms; however, by 1974 eolian landforms occupied only 2 percent of the total area. Similarly the decreased influence of wind tides is shown by the reduction of wind-tidal flats from 16 percent of the total area in 1938 to 11 percent of the area in 1974. These changes in eolian landforms and wind-tidal flats were largely compensated for by preferential floral succession which respectively increased the vegetated dunes and barrier flats and subaqueous grassflats from about 20 percent and 7 percent in 1938 to 38 percent and 19 percent in 1974. Washover areas decreased from 15 percent and 16 percent of the total area in 1938 and 1956 to 11 percent of the area in 1974. Beaches on the Gulf side of the islands also decreased in areal extent as discussed in a previous section.

The increased intensity of human activity between 1938 and 1974 is reflected by the fact that spoil and made land included about 4 percent of the area in 1938, but by 1974 almost 14 percent of the area was encompassed by spoil and made land.

## Description of Changes by Subarea

### North Mustang Island

The areal extent of the individual map units in north Mustang Island subarea (Aransas Pass to Wilson's Cut) is tabulated in table 3; changes in the areal extent of selected map units between 1938 and 1974 are shown in figure 19.

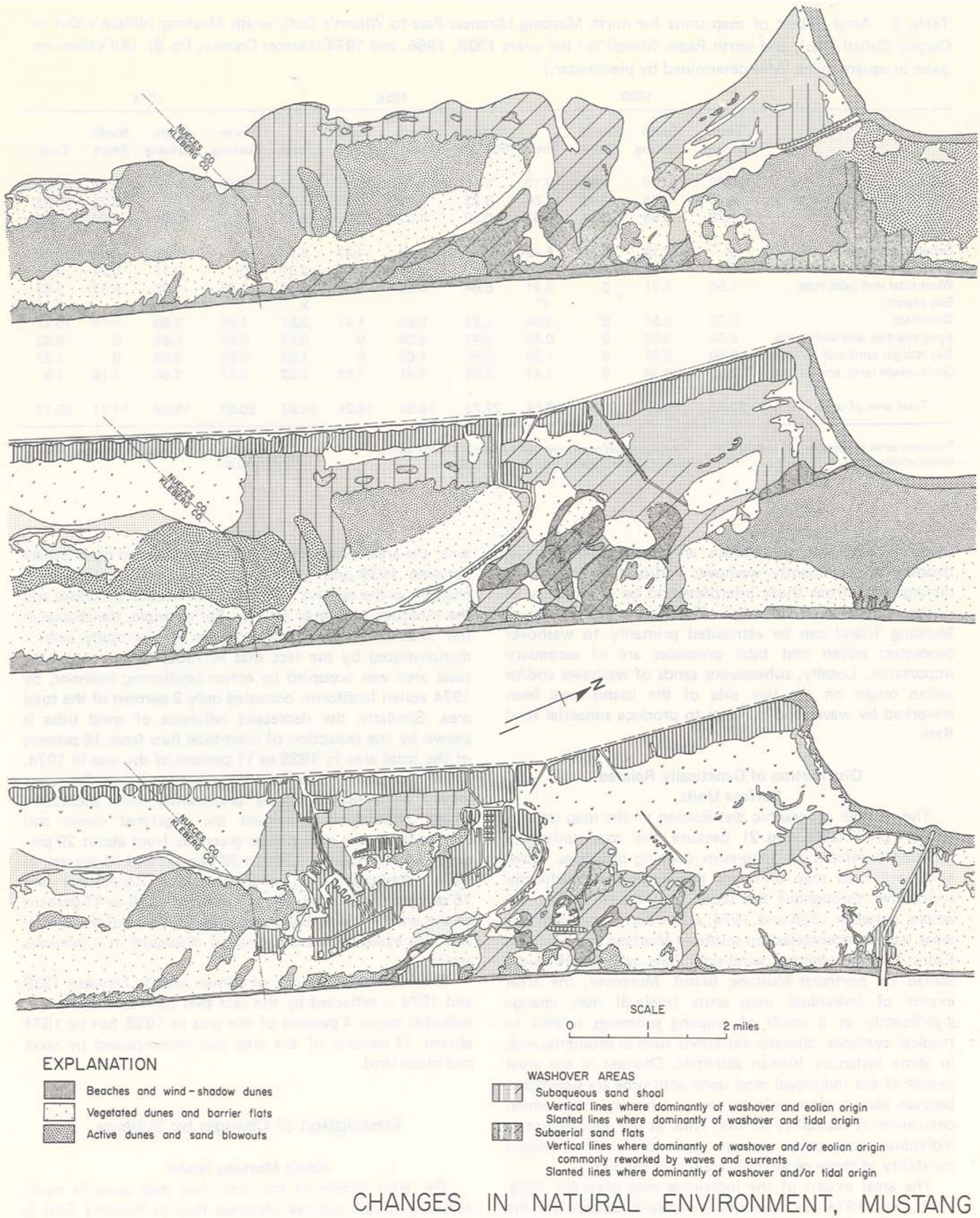
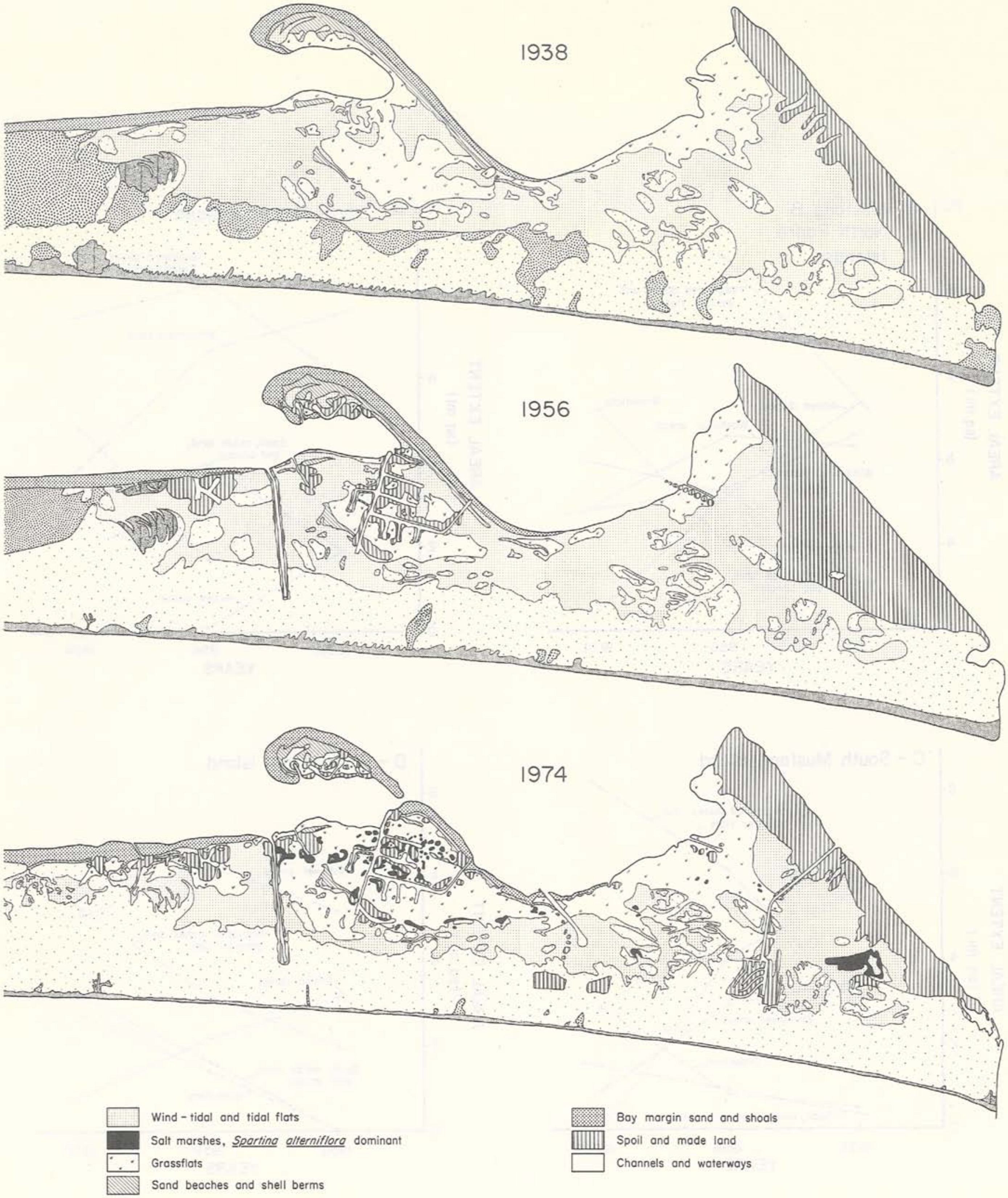



Figure 18. Areal distribution of natural environments on Mustang and north Padre Islands (1938-1974).




AND NORTH PADRE ISLANDS, TEXAS (1938-1974)

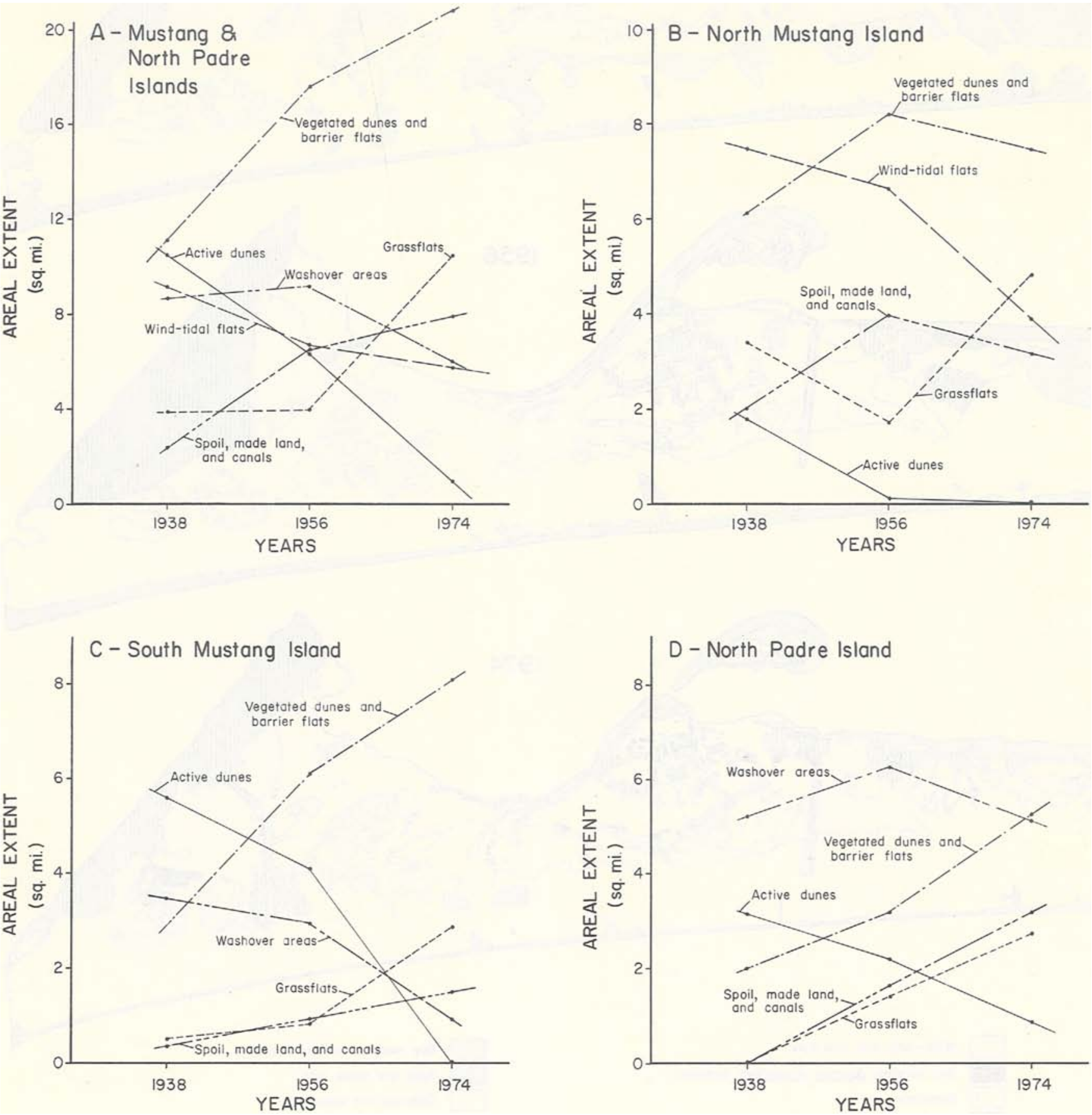



Figure 19. Changes in areal extent of selected environments for total area and by subarea (1938, 1956, 1974).

Between 1938 and 1956, the southward progradation of subaerial spoil disposed along the south side of the Corpus Christi Ship Channel significantly reduced the areal extent of the adjacent wind-tidal flats and grassflats at the northern end of Mustang Island. Although wind-tidal flats were partly reestablished by 1974 in the areas previously covered by spoil, their overall areal extent was reduced by the tremendous expansion of grassflats.

On the southeast side of Shamrock Island and along Mustang Island to the east, grassflats were reduced in areal extent between 1938 and 1956 by the dredging of canals into grassflat areas and by the reworking of spoil derived from the canals. Between 1956 and 1974, however, many of the spoil areas were colonized by grassflats and salt marshes. Moreover, on Mustang Island, grassflats extended into areas formerly occupied by wind-tidal flats.

In 1938, relatively minor active dune areas, oriented perpendicular to the Gulf shoreline and probably originating in washovers locally disrupted the continuity of the vegetated barrier flats along the Gulf side of the island. By 1956, the dune areas had become vegetated.

In summary, the most significant environmental changes in the north Mustang Island subarea between 1938 and 1974 involved changes in the areal extent of wind-tidal flats, grassflats, spoil and made land, active dunes, and vegetated dunes and barrier flats (table 3, fig. 19). Wind-tidal flats, which occupied 33 percent of the total area in 1938 and 29 percent in 1956, occupied only 19 percent of the area in 1974. The reduction in wind-tidal flats between 1938 and 1956 was mainly the result of increased human activity which is reflected by the fact that spoil and made land increased from 9 percent of the total area in 1938 to 18 percent in 1956. The even greater decrease in wind-tidal flats between 1956 and 1974 resulted from the spread of grassflats into former wind-tidal flat areas. In 1938, grassflats occupied 15 percent of the north Mustang subarea but by 1956 their extent had been reduced to 8 percent of the area because of increased human activity. Subsequently, grassflats spread and constituted 23 percent of the north Mustang Island subarea by 1974. Vegetated dunes and barrier flats increased from 27 percent of the total area in 1938 to 36 percent of the total area in 1956. This reflects a decrease in the area occupied by eolian landforms from 8 percent to less than 1 percent of the area. The slight decrease in the area occupied by vegetated dunes and barrier flats between 1956 and 1974 resulted from increased human activity.

### South Mustang Island

In 1938, 34 percent of south Mustang Island (Wilson's Cut to Corpus Christi Pass) was occupied by active dunes. One dune field, comprising 88 percent of the area occupied by eolian landforms, extended parallel to the island trend for a distance of approximately 4.6 miles. This active dune field was at least partly nourished by a broad hurricane washover area, approximately 1.7 miles wide, which interrupted the vegetated fore-island dunes. Between 1938 and 1974, expansion of vegetation, both bayward and parallel to the fore-island dune trend, gradually stabilized the active dune fields. More specifically, between 1938 and 1956 the vegetated dunes and barrier flats, which bordered the dune fields on their seaward side, increased from approximately one-fourth of the width of the island and 18 percent of the south Mustang Island subarea to more than one-half of the width of the island and 36 percent of the subarea. By 1974, the area mapped as vegetated dunes and barrier flats occupied the entire width of the island and 48 percent of the south Mustang Island subarea, and consequently active eolian landforms were restricted to less than 1 percent of the area. The northeastward and southwestward expansion of vegetation between 1938 and 1974 reduced the broad washover area that was present in 1938 to the narrow area now occupied by the fish pass (fig. 18).

In both 1938 and 1974, wind-tidal flats extended into the area occupied by stabilized vegetated dunes and barrier flats. In 1956, however, the tidal flats were not developed although tidal channels extended from Laguna Madre into these same areas.

In 1938, subaqueous sand shoals (presumably of tidal delta, washover, and eolian origin) prevailed over grassflats in Laguna Madre, immediately bayward of the active dune field. By 1956, however, the grassflats in this part of Laguna Madre had increased slightly at the expense of subaqueous sand shoals from 3.5 percent of the south Mustang Island subarea to 4 percent of the area. By 1974, grassflats occupied the majority of this part of Laguna Madre including 17 percent of the total south Mustang Island subarea.

In summary, the most significant environmental changes in the south Mustang Island subarea between 1938 and 1974 involved the decrease in active eolian landforms from 34 percent to 0.02 percent of the total area, and the spread of vegetated dunes and barrier flats from 18 percent to 48 percent of the area. Furthermore, between 1956 and 1974, grassflats increased significantly from 5 percent to 17 percent of the south Mustang Island subarea. The expansion of vegetated dunes and barrier flats and grassflats resulted in a decrease in the area mapped as subaerial and subaqueous washover deposits. Human activity increased in the south Mustang Island area between 1938 and 1974, as reflected by the increase in spoil and made land from 2 percent of the total area in 1938 to 9 percent of the area in 1974. This increase in activity was considerably less than that experienced in the north Padre Island area during this same time, however, and the total area which has been modified by man is small compared to the modifications experienced by both the north Padre and north Mustang Island areas.

### North Padre Island

The north Padre Island subarea extends from Corpus Christi Pass on the north to the Nueces-Kleberg County line on the south. In 1938, 47 percent of the north Padre Island area was dominated by washover characterized by subaqueous sand shoals and subaerial sand flats (29 percent) and active dunes (18 percent); however, by 1974 eolian landforms had become more restricted in areal extent as the result of the expansion of vegetation and occupied only 5 percent of the area. With the spread of vegetation, vegetated dunes and barrier flats gradually expanded in areal extent from 12 percent of the north Padre Island area to 30 percent of the area. In addition to the natural changes in the environment, significant changes caused by human activities are indicated by the dramatic increase in spoil and made land. In 1938, none of the north Padre area was comprised of spoil and made land, whereas in 1974 it comprised 18 percent of the area.

In the Corpus Christi and Newport Pass washover areas, subaerial sand flats of dominantly washover and/or tidal origin accreted bayward between 1938 and 1956 at the expense of subaqueous sand shoals. By 1974, these flats had been locally cut by channels and inundated by bay waters. Vegetative cover on the subaerial sand flats increased slightly between 1938 and 1974.

In 1938, a small area of coppice mounds occurred in the washover area east of Packery Channel and southwest of Newport Pass. The area occupied by the coppice mounds in 1938 may have been washed over by the 5-foot storm surge associated with the 1933 hurricane and most certainly was washed over by the 11.5-foot surge (Price, 1956) associated with the hurricane of 1919. The coppice mounds record the first stage in the reestablishment of dunes in the washed-over area. By 1956, the coppice mounds had grown into moderate-sized dunes but had not yet formed a continuous dune ridge. Dune growth in the area was terminated, however, by community development in 1969.

In 1938, the area southwest of Packery Channel was occupied by an extensive field of active dunes. By 1974, the bayward expansion of vegetation had greatly reduced the area of active dunes from 18 percent of the north Padre area to 5 percent of the area.

On the bay side of the active dune field, extensive subaqueous sand shoals existed in 1938 which are attributed to washover and eolian processes. The most bayward extent of these sand shoals occurred opposite washover channels incised through the active dune area. These channels probably last transported washover sands from the beach and dune area into Laguna Madre during the hurricane of 1919 when a storm surge height of 11.5 feet was reported (table 2). In addition to receiving washover sands, the sand shoals probably also received eolian contributions from the active dunes. The sands comprising the subaqueous sand shoals were apparently locally reworked by waves and currents during northers to form local subaerial sand flats surrounded by subaqueous shoals. Between 1938 and 1974, these subaerial sand flats grew in size, and the shallow subaqueous areas on the island side of the emergent areas were gradually filled in, perhaps mostly by windblown sand derived from the active dune field. By 1974, part of the back-island area formerly occupied by subaqueous sand shoals had become vegetated barrier flats and the site of commercial development.

In summary, the most significant environmental changes in the north Padre Island subarea between 1938 and 1974, which were similar to those which occurred in the south Mustang Island area, involved the reduction in eolian landforms from 19 percent to 5 percent of the total area, the spread of vegetated dunes and barrier flats from 12 percent to 30 percent of the total area, and the increase in spoil and made land from 0 to 18 percent of the total area. Furthermore, between 1938 and 1974, grassflats increased from less than 1 percent of the total area in 1938 to 16 percent of the total area in 1974. The increased expansion of grassflats is partly responsible for the decrease in the area mapped as washover (16 percent of the area in 1956 and 11 percent of the area in 1974). The apparent increase in the areal extent of washover areas between 1938 and 1956 results from incomplete mapping of the north Padre area on the 1938 photographs.

### Summary and Interpretation of Changes

The most significant and widespread changes (fig. 19) on Mustang and north Padre Islands between 1938 and 1974 involved:

1. Reduction in the area occupied by eolian landforms as a result of the gradual stabilization of these areas by vegetation.
2. The spread of subaqueous grassflats into former areas of wind-tidal flats (north Mustang Island) or into areas of subaqueous sand shoals occurring in washover areas (south Mustang and north Padre Islands).
3. Increase in the area occupied by spoil and made land, particularly in the north Padre Island area.

The reduction in eolian landforms and the spread of vegetation on Mustang and north Padre Islands between 1938 and 1974 apparently records a trend to return to a condition last exhibited in the late 1800's. According to Price and Gunter (1943), Padre Island was described as "green as a garden" by the founder of the Kennedy Ranch; the greenness disappeared some time after 1870. Some of the earliest depletion of the vegetational cover recorded began during the droughts from 1880 to 1890 and 1895 to 1905; the denudation of vegetation apparently resulted from a combination of both drought and overgrazing. Price and Gunter (1943) suggested that after the drought periods, increased grazing enhanced evaporation and runoff by thinning the vegetative cover, and discouraged the return of vegetation. Large areas on Padre Island were barren sand and comparable to a desert until 1941. These areas were presumably comparable to the large active dune fields on south Mustang and north Padre Islands in 1938, which comprised 34 percent and 18 percent of these areas, respectively. According to Price and Gunter (1943), some of the depleted vegetational cover was repaired by the unprecedented rainy seasons of 1941 and 1942. In the study area, this vegetational repair apparently continued until 1974, despite intervening periods of drought (Lowry, 1959), and has reduced the area of eolian activity on south Mustang and north Padre Islands to 0.2 percent and 5 percent of their respective areas.

The denudation of vegetative cover in the late 1800's and early 1900's encouraged landward transport of sand by storm surge and winds from the beaches and active dunes into Laguna Madre which has filled rapidly since 1880 (Price and Gunter, 1943). In the study area, this lagoonward transport and deposition of sand by washover and eolian processes is apparent on the 1938 map as evidenced in both the south Mustang and north Padre areas by subaqueous sand shoals on the bay and lagoonward sides of active dune fields traversed by elongate washover areas. Furthermore, much of the filling of the tidal pass area between Mustang and Padre Islands apparently also occurred during this same time. Sometime before 1916, the channel between Padre and Mustang Islands was up to

1 mile wide and 30 feet deep (Writer's Round Table, 1950). The 11.5-foot storm surge (Price, 1956) which accompanied the 1919 hurricane, not only washed over Padre (Price and Gunter, 1943), San Jose (Writer's Round Table, 1950), and presumably Mustang Islands, but also closed the tidal-pass area. Since 1919, the tidal-pass area has been alternately opened and closed (Writer's Round Table, 1950).

The rapid spread of subaqueous grassflats between 1956 and 1974 in the subaqueous sand shoal area lagoonward of south Mustang Island could in part reflect both vegetational repair on the barrier island and less severe storm surge resulting in decreased lagoonward transport and deposition of sand derived from the adjacent dune fields. Such an explanation does not account for the spread of subaqueous grassflats in the north Mustang Island area. Here, grassflats extended into areas formerly occupied by wind-tidal flats, which suggests a rise in water level between 1956 and 1974. Continuous tide data at Galveston since 1904 indicate a trend of sea-level rise or compactional subsidence (Morton, 1974). Any rise which apparently occurred between 1938 and 1956 at Port Aransas is not reflected by detectable changes in the distribution of the environmental map units in the study area. In fact, the extent of wind-tidal flats in conjunction with the general appearance of the area in 1956 supports the idea that sea level was slightly lower during the mid-1950's.

The increase in human activity in the study area, reflected by the increased area occupied by spoil and made land, generally resulted in the destruction of natural environments. Locally, natural environments eventually reoccupied spoil areas from which they had formerly been displaced. Moreover, in the north Mustang Island area, spoil was partly colonized by salt marshes not previously present in these areas before human modification of the natural environment.

## SHORELINE CHANGES

Certain risks accompany ownership and development of ocean front, lake front, or bayside property. Flooding and shoreline erosion rank high among the risks involved. In many areas worldwide, property owners have become acutely interested in and painfully aware of shoreline changes and attendant losses and gains in real estate. Thus the increased development of waterfront property necessitates the historical documentation of these hazards and presentation of the data as part of a public awareness program which, hopefully, would minimize physical and economic losses attributed to the natural hazards.

The technique of historical monitoring was used to monitor erosion and accretion of the Gulf and bay shorelines, as well as the fore-island vegetation line. The general methods and procedures used by the Bureau of Economic Geology in its historical shoreline monitoring program are presented in appendix A.

### LATE QUATERNARY TIME

Significant changes in sea level have occurred along the central Texas coast during the past 10,000 years (Shepard, 1956, 1960). Prominent ridge-and-swale topography from abandoned beach ridges, visible on aerial photographs of San Jose and Shamrock Islands attest to the fact that accretion was predominant after sea level reached its stillstand position about 3,000 years before present (BP). Radiocarbon methods (Shepard, 1956, 1960) provide dates for the interpretation of sea-level positions prior to stillstand.

According to Shepard (1956, 1960), barrier-island development along the central Texas coast was initiated about 6,500 years ago. Vertical accretion of the barrier islands attendant with sea-level rise was augmented by eolian processes. Lateral accretion accompanied landward transport of sediment from the inner shelf as well as shell and sediment transported from the bottom of Corpus Christi Bay. Progradation of the barrier island into Corpus Christi Bay was associated with hurricane washover and eolian processes.

During the past several hundred years, conditions that promoted seaward and bayward accretion of the barrier islands have been altered both naturally and more recently to some extent by man. Consequently, sediment supply to the Texas coast has diminished, and shoreline erosion is generally prevalent.

### GULF SHORELINE CHANGES

Changes between 1860 and 1964 along the Gulf shoreline of Mustang and north Padre Islands were determined by Morton and Pieper (1977) from the analysis of measurements made at 22 arbitrary points (table 4) spaced 5,000 feet apart along the base map (fig. 20). In general, mapped shorelines indicate three periods of erosion (1860-82 to 1937, 1958-59 to 1969-70, 1969-70 to 1974) and one period of accretion (1937 to 1958-59). A detailed analysis of specific changes for these different periods is presented by Morton and Pieper (1977); only the net historic changes from 1860-82 to 1974 are treated in this report.

*Net historic change (1860-82 to 1974).*—Net shoreline changes over the 92 to 107-year period were predominantly

Table 4. Gulf shoreline changes (from Morton and Pieper, 1977).

| Mustang and north Padre islands | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Net Time | Net Distance | Net Rate |
| 1 | 1860-66 1937 | +1650 | +22.3 | 1937 1958 | + 50 | + 2.3 | 1958 1970 | - 25 | - 2.2 | 1970 1974 | - 75 | - 18.7 | 1860-66 1974 | +1600 | + 14.4 |
| 2 | 1867 1937 | +1025 | +14.6 | ″ | - 25 | - 1.2 | ″ | - 125 | - 10.9 | ″ | - 50 | - 12.5 | 1867 1974 | + 825 | + 7.7 |
| 3 | ″ | + 500 | + 7.1 | ″ | -<10 | -<1.0 | ″ | - 175 | - 15.2 | ″ | + 25 | + 6.2 | ″ | + 350 | + 3.3 |
| 4 | ″ | + 75 | + 1.1 | ″ | +125 | + 5.8 | ″ | - 175 | - 15.2 | ″ | - 100 | - 25.0 | ″ | - 75 | -< 1.0 |
| 5 | ″ | - 75 | - 1.1 | ″ | + 50 | + 2.3 | 1958 1969 | - 125 | - 11.4 | 1969 1974 | - 100 | - 22.2 | ″ | - 250 | - 2.3 |
| 6 | ″ | - 50 | -<1.0 | ″ | - 25 | - 1.2 | ″ | - 125 | - 11.4 | ″ | - 75 | - 16.7 | ″ | - 275 | - 2.6 |
| 7 | ″ | - 100 | - 1.4 | ″ | - 50 | - 2.3 | ″ | - 50 | - 4.5 | ″ | - 100 | - 22.2 | ″ | - 300 | - 2.8 |
| 8 | ″ | - 125 | - 1.8 | ″ | - 25 | - 1.2 | ″ | - 75 | - 6.8 | ″ | - 125 | - 27.8 | ″ | - 350 | - 3.3 |
| 9 | ″ | - 175 | - 2.5 | ″ | +150 | + 7.0 | ″ | - 100 | - 9.1 | ″ | - 125 | - 27.8 | ″ | - 250 | - 2.3 |
| 10 | ″ | - 225 | - 3.2 | ″ | +175 | + 8.1 | ″ | - 25 | - 2.3 | ″ | - 200 | - 44.4 | ″ | - 275 | - 2.6 |
| 11 | ″ | - 200 | - 2.9 | ″ | + 75 | + 3.5 | ″ | -< 10 | -< 1.0 | ″ | - 200 | - 44.4 | ″ | - 325 | - 3.0 |
| 12 | ″ | - 125 | - 1.8 | ″ | +100 | + 4.6 | ″ | - 25 | - 2.3 | ″ | - 200 | - 44.4 | ″ | - 250 | - 2.3 |
| 13 | ″ | - 100 | - 1.4 | ″ | +100 | + 4.6 | ″ | 0 | 0 | ″ | - 225 | - 50.0 | ″ | - 225 | - 2.1 |
| 14 | ″ | - 75 | - 1.1 | ″ | +100 | + 4.6 | ″ | +< 10 | +< 1.0 | ″ | - 225 | - 50.0 | ″ | - 200 | - 1.9 |
| 15 | ″ | - 50 | -<1.0 | ″ | +175 | + 8.1 | ″ | - 50 | - 4.5 | ″ | - 150 | - 33.3 | ″ | - 75 | -< 1.0 |
| 16 | 1862 1937 | - 100 | - 1.3 | ″ | +150 | + 7.0 | ″ | 0 | 0 | ″ | - 150 | - 33.3 | 1862 1974 | - 100 | -< 1.0 |
| 17 | ″ | - 100 | - 1.3 | ″ | +150 | + 7.0 | ″ | - 50 | - 4.5 | ″ | - 125 | - 27.8 | ″ | - 125 | - 1.1 |
| 18 | 1882 1937 | - 125 | - 2.3 | ″ | + 50 | + 2.3 | ″ | - 75 | - 6.8 | ″ | - 200 | - 44.4 | 1882 1974 | - 350 | - 3.8 |
| 19 | ″ | - 100 | - 1.8 | ″ | + 75 | + 3.5 | ″ | - 50 | - 4.5 | ″ | - 200 | - 44.4 | ″ | - 275 | - 3.0 |
| 20 | ″ | - 25 | -<1.0 | 1937 1959 | 0 | 0 | 1959 1969 | 0 | 0 | ″ | - 100 | - 22.2 | ″ | - 125 | - 1.4 |
| 21 | ″ | + 550 | +10.0 | ″ | 0 | 0 | ″ | 0 | 0 | ″ | - 125 | - 27.8 | ″ | + 425 | + 4.6 |
| 22 | ″ | - 450 | - 8.2 | ″ | + 25 | + 1.1 | ″ | 0 | 0 | ″ | - 75 | - 16.7 | ″ | - 500 | - 5.4 |

+accretion
-erosion

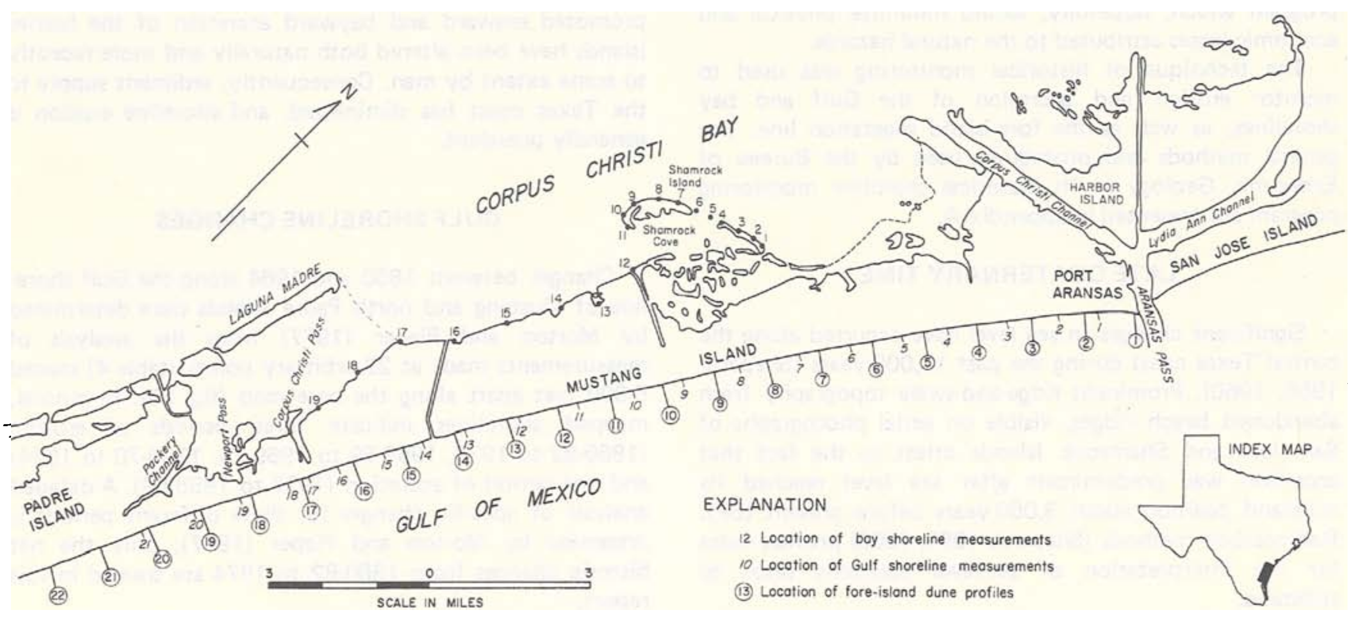



Figure 20. Locations of dune profiles and points of measurement for shoreline changes.

erosional. As indicated by the data in table 4, net erosion was recorded at 18 points, whereas net accretion was recorded at only 4 points.

Specifically, net accretion occurred between points 1 and 3 as a result of inlet migration and concomitant outbuilding of the north end of Mustang Island. Furthermore, construction of the jetties at Aransas Pass promoted additional shoreline accretion by entrapment of sediment. Net accretion of 425 feet at point 21 was associated with the closing of Packery Channel. Net erosion for the study area ranged from 75 to 500 feet; average net erosion was about 245 feet. At most points, the net rate of change was relatively low, less than 3 feet per year. But obviously short-term changes occurred at much higher rates where the shoreline experienced both accretion and erosion. A disturbing fact is the erosional trend established after 1958 which continued up to 1974.

## BAY SHORELINE CHANGES

### Definition of Bay Shoreline Study Area

The Gulf shoreline appearing on the early topographic charts published by the U.S. Coast Survey represents the mean high-water line which has been defined as "the average height of all the high waters at the place over a considerable period of time" and does not include storm tides (Shalowitz, 1964, p. 174).

There are serious difficulties in applying this definition along bay shorelines because of extant marshes, wind-tidal flats, and gently sloping sandy shoals that preclude the precise location of the high-water line. Marshes may be in various stages of growth—from young and mostly submerged to more developed and subaerially exposed. The early coastal surveyors solved this problem as described by Shalowitz (1964, p. 177).

> In surveying such areas, the Bureau has not deemed it necessary to determine the actual high water line, but rather the outer or seaward edge of the marsh, which to the navigator would be the dividing line between land and water.

The same procedure has been followed in marshy areas mapped on aerial photographs for the present study. In wind-tidal flat areas, the bay shoreline was defined as the outer or bayward edge of the wind-tidal flat.

In this manner, those areas that are inundated only by wind tides are included as part of the barrier system, and apparent erosion caused by wind tides are not considered in shoreline-trend calculations.

In areas where sandy beaches and berms occur, the bay shoreline was determined on the same basis as Gulf shorelines. In every case, care was taken to ensure that the same criteria were used at each locality for determining the bay shoreline position on each succeeding set of photographs or maps.

Bay shoreline changes between 1867 and 1974 were studied in detail for two major sections of Mustang Island (fig. 20). The areas chosen are continuous stretches of the island that have an easily recognized and delineated shoreline. This choice, in effect, excludes most wind-tidal flats and marshy areas where the bay shoreline varies with changes in subaqueous shoals and marsh vegetation.

The first area of study is Shamrock Island (points 1 through 11)—a spit projecting into Corpus Christi Bay along north Mustang Island. Historical monitoring data were determined by measurements at 11 stations spaced 1,500 feet apart along the map of the present shoreline. The second area of study is south Mustang Island where stations (12 through 19) were located at 5,000-foot intervals.

*1867 to 1937.*—Between 1867 and 1937, stations 1 through 7 on Shamrock Island experienced erosion that ranged from 25 to 290 feet (table 5). In contrast, accretion increased from 50 feet at point 8 to 600 feet at point 10. The bay shoreline at point 11 remained relatively unchanged.

The pattern of erosion near the north and concomitant accretion farther south can be related to the north-south wind-generated currents within Corpus Christi Bay. Sediment eroded from northern Shamrock Island was subsequently deposited near the southern tip of the island. Apparently very little change occurred in the Shamrock Cove area during this time period.

During this same time period, points 15 through 19 experienced accretion, and points 12 through 14 experienced erosion. Accretion between stations 15 and 19 can be attributed to the bayward migration of devegetated sand dunes that were active during the late 1800's and early 1900's. The prevailing southeasterly wind caused migration of the dunes across the island and into Laguna Madre and Corpus Christi Bay. This process of bay shoreline accretion due to eolian transport of sand has been well documented in Texas by Price and Gunter (1943), Fisk (1959), and more recently by Hunter and Dickinson (1970) who stated that portions of north Padre Island advanced an average of 700 feet into Laguna Madre between 1948 and 1967.

Price and Gunter (1943) reported that hurricane washover may also have contributed to devegetation in the north Padre Island area. In 1942, parts of north Padre had "no grass" because of severe salt-water flooding in 1933. This same storm also opened up present-day Packery and Newport Channels. Since that time, however, the southern portions of Mustang Island have been revegetated, and the westward movement of sand has been greatly decreased.

The shoreline segment between points 12 and 14 was north of the active dune field of the previous segment and bayward of a wind-tidal-flat area. Currents created by strong northerly winds blowing across Corpus Christi Bay probably contributed to erosion along this segment of the bay shoreline which received little additional sediment from either the barrier island to the east or Shamrock Cove to the north.

*1937 to 1958.*—Bay shoreline changes between 1937 and 1958 were dominated by accretion and equilibrium. Anomalous erosion occurred at point 15 and the shoreline remained unchanged at points 13 and 18. Accretion at the other points ranged from 100 to 1,150 feet; however, most points experienced accretion of 100 to 300 feet.

Some of this accretion can be attributed to dredging and channelling activities which occurred in the vicinity of Shamrock Island in the mid-1950's. Spoil was deposited at

Table 5. Bay shoreline changes.

Mustang Island

| Point | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Net Time | Net Distance | Net Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1867 | | | 1937 | | | 1958 | | | 1867 | | |
| 1 | 1937 | - 25 | - < 1.0 | 1958 | + 300 | +14.3 | 1974 | - 450 | - 28.1 | 1974 | - 175 | - 1.6 |
| 2 | ″ | - 90 | - 1.3 | ″ | + 375 | +17.8 | ″ | - 425 | - 26.6 | ″ | - 140 | - 1.3 |
| 3 | ″ | - 110 | - 1.6 | ″ | + 290 | +13.8 | ″ | - 325 | - 20.3 | ″ | - 145 | - 1.4 |
| 4 | ″ | - 100 | - 1.4 | ″ | + 150 | + 7.1 | ″ | - 500 | - 31.2 | ″ | - 450 | - 4.2 |
| 5 | ″ | - 290 | - 4.1 | ″ | + 290 | +13.8 | | breached | | | | |
| 6 | ″ | - 210 | - 3.0 | ″ | + 290 | +13.8 | | ″ | | | | |
| 7 | ″ | - 175 | - 2.5 | ″ | + 175 | + 8.3 | ″ | - 400 | - 25.0 | ″ | - 400 | - 3.7 |
| 8 | ″ | + 50 | +< 1.0 | ″ | + 100 | + 4.8 | ″ | - 310 | - 19.4 | ″ | - 160 | - 1.5 |
| 9 | ″ | + 280 | + 4.0 | ″ | + 100 | + 4.8 | ″ | - 380 | - 23.7 | ″ | 0 | 0 |
| 10 | ″ | + 600 | + 8.6 | ″ | + 175 | + 8.3 | ″ | - 175 | - 10.9 | ″ | + 600 | + 5.6 |
| 11 | ″ | 0 | 0 | ″ | +1150 | +54.8 | ″ | - 340 | - 21.2 | ″ | + 810 | + 7.6 |
| 12 | ″ | - 425 | - 6.1 | ″ | + 700 | +33.3 | ″ | - 425 | - 26.6 | ″ | - 150 | - 1.4 |
| 13 | ″ | - 390 | - 5.6 | ″ | 0 | 0 | ″ | - 1100 | - 68.7 | ″ | - 1490 | - 13.9 |
| 14 | ″ | - 1050 | - 15.0 | ″ | + 450 | +21.4 | ″ | - 900 | - 56.2 | ″ | - 1500 | - 14.0 |
| 15 | ″ | + 225 | + 3.2 | ″ | - 25 | - 1.2 | ″ | - 175 | - 10.9 | ″ | + 25 | +< 1.0 |
| 16 | ″ | + 550 | + 7.9 | ″ | + 300 | +14.3 | ″ | - 600 | - 37.5 | ″ | + 250 | + 2.3 |
| 17 | ″ | +1750 | + 25.0 | ″ | + 600 | +28.6 | ″ | - 800 | - 50.0 | ″ | +1550 | + 14.5 |
| 18 | ″ | +1925 | + 27.5 | ″ | 0 | 0 | ″ | + 125 | + 7.8 | ″ | +2050 | + 19.2 |
| 19 | ″ | + 575 | + 8.2 | ″ | + 225 | +10.7 | ″ | - 180 | - 11.2 | ″ | + 620 | + 5.8 |

+ accretion
- erosion

stations 1, 2, 9, and 11, and additional sediment suspended by the dredging activities may have contributed to accretion at other points. A pronounced altering of Shamrock Cove because of dredging occurred during this period.

The widespread accretion between 1937 and 1958 was not restricted to the Mustang and Shamrock Island areas but occurred on the Gulf shoreline also. Some of the bay shoreline accretion can be attributed to placement of spoil, but this does not account for all the accretion nor for its widespread and relatively consistent nature.

There are several possible explanations for a period of general accretion such as the one experienced along the central Texas coast between 1930 and 1958. An influx of additional sediment into the area from a nearby source such as a river could produce such an effect. In the Mustang Island area, however, no new sediment sources are apparent; in fact, recent increases in the amount of erosion on Mustang and San Jose Islands suggest that the amount of sand available is actually decreasing. It is also unlikely that any new influx of sediment could affect such widely spaced areas in such a similar manner.

Another explanation for the anomalous accretion would be unusual meteorological conditions. Strong southeast winds could blow water away from the bay shoreline and produce an apparent accretion. However, these winds would not account for the observable accretion on both the Gulf and bay shorelines (as is the case).

Perhaps the most likely explanation is that the apparent accretion during this period is partly caused by a regional lowering of sea level. If sea level were lower, it would appear as if accretion had occurred on both the Gulf and bay shorelines.

A relative sea-level curve for Galveston, Texas, (fig. 21) shows a relatively lower sea level in the mid-1950's. This curve is for Galveston, Texas, where significant subsidence has occurred since the 1940's. On Mustang Island, a similar lowering of sea level with essentially no subsidence could produce apparent changes in the Gulf and bay shorelines. This sea-level lowering during the 1950's is therefore postulated as a mechanism to account in part for the accretionary trend shown during the period 1937-1958.

*1958 to 1974.*—Between 1958 and 1974, all stations experienced erosion, with the exception of station 15 where accretion occurred. Station 18 is located on a wind-tidal flat bordering on sandy subaqueous shoals in shallow Laguna Madre, where shifting sand and variable tidal ranges in Laguna Madre could account for this accretion. The erosion experienced at the other localities may be partly caused by a general rise in sea level following the low period in the mid-1950's. Human activities also contributed to the erosion. This is particularly evident at station 7, which is adjacent to a dredging operation completed in the mid-1950's. The subsequent slumping and erosion of unconsolidated spoil piles has contributed to a net loss of shoreline at this point. Southerly longshore currents within the bay added to the erosion as they carried sediment away, whereas no new sediment was brought in except locally at the bayward termination of the fish pass. Specific changes in the bay shoreline attributed to operation of the fish pass were discussed by Behrens and Watson (1974).

Examination of aerial photographs indicates that Shamrock Island was breached at stations 5 and 6 sometime between 1969 and 1971. This probably occurred during Hurricane Celia in 1970. The currents flowing through the breach built a southward-projecting spit at station 4.

*Net historic changes (1867 to 1974).*—The net changes in bay shoreline on Shamrock Island are varied. Net erosion

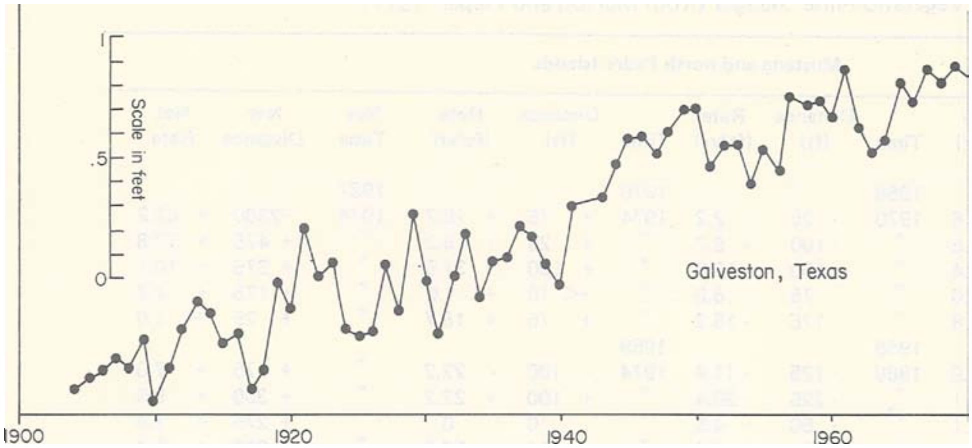



Figure 21. Relative sea-level changes based on tide gage measurements for Galveston, Texas. Data from Gutenberg (1941), Marmer (1951), and Swanson and Thurlow (1973).

occurred at stations 1 through 8; the island was breached at stations 5 and 6, and net accretion was recorded at stations 10 and 11. Station 9, which exhibited no net change, represents the inflection point or demarcation from net erosion to net accretion. This reversal in trend along the bay shoreline is caused by the erosion of sediment from north Shamrock Island and deposition at the tip of the island, extending the tip by spit accretion.

Net erosion was also recorded at stations 12 through 14, whereas net accretion occurred at points 15 through 19. The net accretion at stations 15 through 19 is mostly attributed to the gradual extension of the shoreline into Laguna Madre by washovers and windblown sand; however, the eolian transport has practically been eliminated in recent years.

Except for unusual circumstances such as the eolian activity and the apparent secular variation in sea level, the data indicate that bay shoreline erosion will probably continue, especially from point 1 to point 9 and between points 12 and 17. Erosion is anticipated in these areas because of the fetch across Corpus Christi Bay and the shoreline orientation and the wind direction during winter storms. Furthermore, the narrow bay-margin platform permits greater wave energy along these segments of the bay shoreline. Perhaps another factor contributing to the erosion is the disruption of the shallow subaqueous sandbars that parallel the bay shoreline. The continuity of these bars was eliminated by dredging of drilling-barge locations during oil field development. The sandbars serve as a transport mechanism for the onshore-offshore and alongshore movement of sediment. Because elimination or termination of the bars prevents or greatly retards sediment transport along the bay shoreline, such activities may translate to increased erosion.

## CHANGES IN POSITION OF VEGETATION LINE

Changes in the Gulf vegetation line are considered independently from shoreline changes because, in many instances, the nature of change and rate of shoreline and vegetation line should not be viewed as a couplet with fixed horizontal distance; this is illustrated in figure 22. Although response of the shoreline and vegetation line to long-term changes is similar, a certain amount of independence is exhibited by the vegetation line because it reacts to a different set of processes than does the shoreline. Furthermore, documentation of changes in vegetation line for this particular study draws on comparison of more aerial photographs than does documentation of shoreline changes (appendix B).

Accurate information on position of vegetation line is available neither for the middle 1800's nor for the early 1900's. Therefore, accounts of changes in vegetation line are restricted to the time period covered by aerial photographs (1937-1974). In general, each period monitored presented a different picture of change as one period of advancement (1937 to 1958-59), one period of retreat (1958-59 to 1969-70), and one period of both advancement and retreat (1967-70 to 1974) were recorded. As with the Gulf shoreline changes, only net changes are discussed in this report. A much more detailed treatment of change in the vegetation line is presented by Morton and Pieper (1976).

### Net Historic Change

Net changes in vegetation line were calculated as they were for shoreline changes. It should be emphasized that shifts in vegetation line are related primarily to storms and recovery during intervening years. Nonetheless, the general trend of change in vegetation line has been net accretion primarily because of the advances that occurred between 1937 and 1958-59. The 1958-59 vegetation line occupied the most seaward position at the greatest number of points monitored. Except for net retreat of 175 feet at point 13, all points experienced net accretion on Mustang and north Padre Islands. Net accretion ranged from 25 to 2,300 feet. Greater amounts were between points 1 and 3 (table 6) where the shoreline accreted as well as in revegetated washover and blowout areas. Net accretion in areas unaffected by such drastic changes was 250 feet or less.

In general, the long-term change in position of the vegetation line is similar to that of the shoreline. Short-term changes in position of the vegetation line, however, reflect climatic conditions and occur independently of shoreline changes. Thus, the horizontal separation between shoreline and vegetation line displays short-term variation (fig. 22).

Table 6. Vegetation-line changes (from Morton and Pieper, 1977).

| Point | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Time | Distance (ft) | Rate (ft/yr) | Net Time | Net Distance | Net Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mustang and north Padre Islands** | | | | | | | | | | | |
| | 1937 | | | 1958 | | | 1970 | | | 1937 | | |
| 1 | 1958 | +2250 | +104.6 | 1970 | - 25 | - 2.2 | 1974 | + 75 | + 18.7 | 1974 | +2300 | + 62.2 |
| 2 | " | + 550 | + 25.6 | " | - 100 | - 8.7 | " | + 25 | + 6.2 | " | + 475 | + 12.8 |
| 3 | " | + 375 | + 17.4 | " | - 150 | - 13.0 | " | + 150 | + 37.5 | " | + 375 | + 10.1 |
| 4 | " | + 250 | + 11.6 | " | - 75 | - 6.5 | " | +< 10 | +< 1.0 | " | + 175 | + 4.7 |
| 5 | " | + 125 | + 5.8 | " | - 175 | - 15.2 | " | + 75 | + 18.7 | " | + 25 | +< 1.0 |
| | | | | 1958 | | | 1969 | | | | | |
| 6 | " | + 300 | + 13.9 | 1969 | - 125 | - 11.4 | 1974 | - 100 | - 22.2 | " | + 75 | + 2.0 |
| 7 | " | + 475 | + 22.1 | " | - 225 | - 20.4 | " | + 100 | + 22.2 | " | + 350 | + 9.5 |
| 8 | " | + 325 | + 15.1 | " | - 50 | - 4.5 | " | 0 | 0 | " | + 275 | + 7.4 |
| 9 | " | + 375 | + 17.4 | " | - 75 | - 6.8 | " | - 100 | - 22.2 | " | + 200 | + 5.4 |
| 10 | " | + 150 | + 7.0 | " | - 25 | - 2.3 | " | - 75 | - 16.7 | " | + 50 | + 1.3 |
| 11 | " | + 225 | + 10.5 | " | + 50 | + 4.5 | " | - 100 | - 22.2 | " | + 175 | + 4.7 |
| 12 | " | +1600 | + 74.4 | " | 0 | 0 | " | - 100 | - 22.2 | " | +1500 | + 40.5 |
| 13 | " | - 175 | - 8.1 | " | 0 | 0 | " | 0 | 0 | " | - 175 | - 4.7 |
| 14 | " | + 175 | + 8.1 | " | +475 | +43.2 | " | +< 10 | +< 1.0 | " | + 650 | + 17.6 |
| 15 | " | | | " | - 150 | - 13.6 | " | 0 | 0 | | | |
| 16 | " | + 800 | + 37.2 | " | 0 | 0 | " | + 400 | + 88.9 | " | +1200 | + 34.3 |
| 17 | " | + 850 | + 39.5 | " | +200 | +18.2 | " | - 100 | - 22.2 | " | + 950 | + 25.7 |
| 18 | " | | | " | - 125 | - 11.4 | " | + 50 | + 11.1 | | | |
| 19 | " | Packery Channel | | | | | | | | | | |
| | 1937 | | | 1959 | | | | | | | | |
| 20 | 1959 | +2200 | +100.0 | 1969 | - 300 | - 28.6 | " | + 75 | + 16.7 | " | +1975 | + 53.4 |
| 21 | " | + 375 | + 17.0 | " | +325 | +30.9 | " | + 125 | + 27.8 | " | + 825 | + 22.3 |
| 22 | " | + 250 | + 11.4 | " | | | | | | " | + 650 | + 17.6 |

+advancement
-retreat

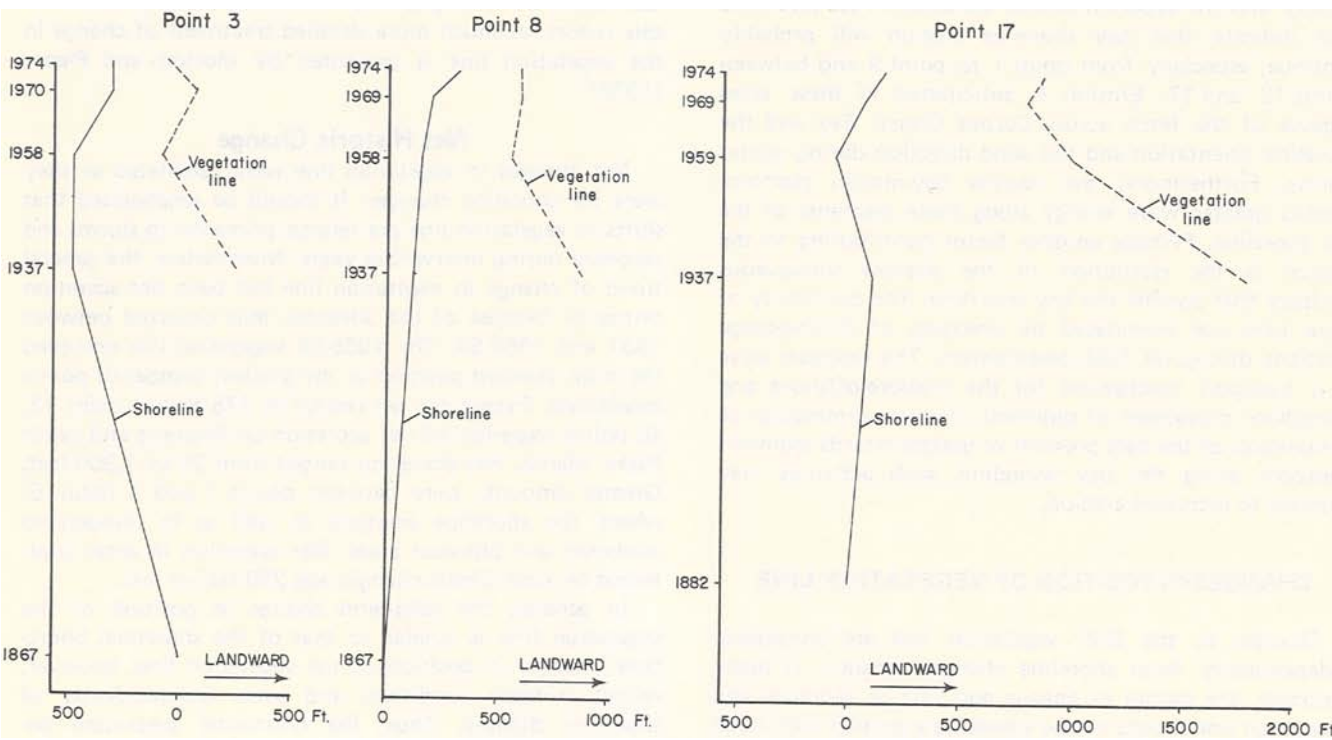



Figure 22. Relative changes in position of shoreline and vegetation line at selected locations (from Morton and Pieper, 1977).

# DUNE CRITICALITY

The Texas coast is struck by a hurricane an average of once every 1.5 years (Hayes, 1967), and it is primarily the beach and dunes that provide protection for back-island areas from the full force of storm surge, wave action, and flooding. With the increased development of Texas coastal barriers and, in particular, the prime beach-dune area, a need has developed to examine the importance of the dunes in storm protection.

The purposes of this study are (1) to review the factors that are critical to the maintenance of protective dunes along coastal barrier islands, (2) to describe the various dune types present on these barriers, (3) to consider their functional relationship in responding to the forces of nature, particularly storms, and (4) to describe the relative importance of each dune type in protecting both the natural coastal system and man's barrier-island developments within that system. By considering the natural processes at work in the Coastal Zone, it is possible to determine how best to develop the coast and at the same time minimize the dangerous and costly confrontations between man and the sea that so often occur.

## SAND DUNE PROTECTION BILL

In 1973, the 63d Texas Legislature passed a landmark Sand Dune Protection Bill (Senate Bill 268) (General Land Office of Texas and Texas Coastal and Marine Council, 1974). With this legislation, it was recognized that both natural and artificial vegetated sand dunes protect the barrier island and peninsulas of Texas from storm waves and waters and that both developments and recreational vehicles have been detrimental to the well-being of these dunes. The act provided that the commissioners of any county north of the Mansfield Ship Channel may establish a sand dune protection line. Maximum extent of the dune protection line is limited to 1,000 feet landward of the mean high-water line. For the purpose of delineating areas with different restrictions, the bill divides the coast into three segments. On the upper coast (Sabine Pass to Aransas Pass), removal of dune sand or destruction of dune vegetation requires a permit. Between Aransas Pass and Mansfield Channel, dunes are protected to the extent that reduction in elevation below that shown on the special flood-hazard map prepared by the Federal Insurance Administration is prohibited. Activities which would destroy the vegetation require a permit as well as provisions for dune stabilization. Operation of recreational vehicles on dunes seaward of the dune protection line is also prohibited in both areas. The bill does not apply south of Mansfield Channel.

Permits are granted after evaluation of applications indicates that the function of the dunes would not be weakened. Activities not covered by the bill include (1) livestock grazing, (2) oil and gas production, and (3) recreational activity other than that relating to recreational vehicles.

The General Land Office of Texas is charged with the responsibility of delineating critical dune areas related to the protection of State land. Nueces County, the first county to establish a dune-protection line under this bill, chose to include the entire area 1,000 feet landward from mean high water.

## PREVIOUS WORK

Several experimental studies have recently been completed on sand dunes of the Texas coast. Gage (1970) used picket snow fencing and old car bodies in an attempt to build artificial dunes in a washover complex on south Mustang Island and on Galveston Island adjacent to San Luis Pass. The experiment was moderately successful in trapping sand, but the incipient dunes were washed away by Hurricane Beulah (1967) and an unusual Gulf storm in February of 1969.

A comprehensive report on a 5-year study of methods for the use of beach grass to construct and stabilize foredunes on the Texas Gulf Coast has recently been completed by the Gulf Universities Research Consortium (Dahl and others, 1974). The best results were obtained by transplanting bitter panicum and sea oats onto the back beach, where these plants trapped and stabilized moving sand.

## BARRIER TYPES AND THEIR RESPONSE TO STORMS

For the purpose of comparing Mustang and north Padre Islands to other barriers, it is useful to consider two end members in the spectrum of modern barrier types, based on their response to storms. Because these barrier types respond differently to storms, they should not be managed or developed in the same manner.

The first end member is the *high-profile island* (fig. 23) characterized by elevations of greater than 10 feet and one or more well-developed, continuous fore-island dune ridge. Commonly, there are smaller discontinuous hummocky foredunes seaward of the first dune ridge and smaller wind shadow or coppice dunes on the back beach seaward of the hummocky foredunes. The height and continuity of these dunes prohibit overwash from flowing randomly across the island, but restrict it to relatively narrow and permanent washover sites that are reopened by storms. Where there is sufficient rainfall, the protected back-island area behind the dunes becomes densely vegetated and is generally flooded only from the bay side of the island during the ebb surge following hurricanes.

The *low-profile island* (fig. 23) is characterized by elevations of less than 10 feet and normally consists of low coppice mounds and discontinuous fore-island dunes. These discontinuous dunes allow storm surge to pass across the island by flowing in and around the scattered dunes like water rushing through a maze. These washovers may form coalescing fan systems along the backside of the islands, and each new storm adds more sediment to the older fans. Overwash is not necessarily restricted to the same pathway during each storm, but it often inundates large areas of the island. Godfrey and Godfrey (1973) discussed the difficulties encountered in North Carolina when the limitations in developing a low-profile island were not recognized.

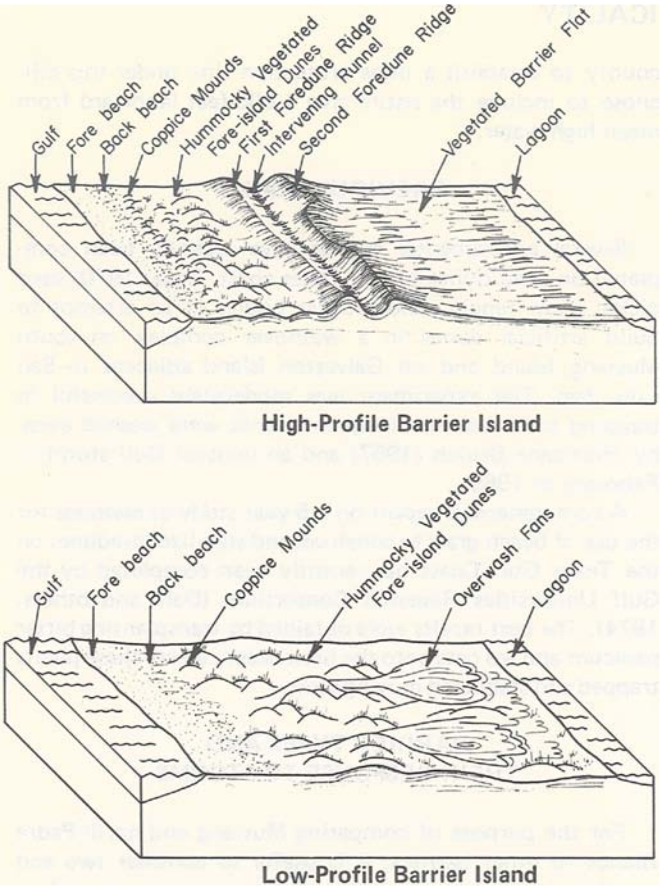



Figure 23. Generalized diagram of high- and low-profile barrier islands typical of Mustang/North Padre and Central/South Padre, respectively.

## MUSTANG AND NORTH PADRE ISLANDS

### Dune Types and Functional Relationships

Mustang and Padre Islands are high-profile islands with high fore-island dune ridges that extend almost the length of the islands. In historic time, Mustang Island has not been breached by washover where the dune ridge is present; however, Corpus Christi Pass, Newport Pass, and Packery Channel are frequently opened by storms.

To understand the protective role that dunes play, it is necessary to consider their function in response to storms. Hurricanes and major storms probably produce the greatest and most sudden changes in the coastline, and the greatest geologic effects of hurricanes are caused by wind-driven waves and storm surge (Hayes, 1967). A cubic yard of water weighs about three-fourths of a ton, and a breaking wave may move forward at speed as great as 50 to 60 mph (Dunn and Miller, 1964). The erosive effects of waves can be greatly increased when they ride the crest of a large storm surge because increased water elevations subject greater portions of the island to wave action.

It is important to note, when considering the effects these processes have on the coast, that the Coastal Zone is a complex system of interrelated environments. No one environment can be altered without affecting adjacent environments. For example, a groin built perpendicular to the beach can cause a sand deficiency on the beach which in turn, could also affect the dunes. Likewise, no single environment can be studied without considering its relationship to the surrounding environments.

An idealized profile of Mustang Island illustrates the various dune types and their distribution (fig. 2). There are six major dune types present in the study area: (1) low, unvegetated or sparsely vegetated coppice mounds, (2) hummocky, discontinuous vegetated fore-island dunes, (3) a continuous vegetated fore-island dune ridge, (4) active dunes and blowouts, (5) stable blowouts, and (6) back-island dunes. Discontinuous and continuous fore-island dunes (pl. 1) have been grouped as one unit, but for the purpose of this discussion of the function of the different dune types, they are considered separately.

In the idealized profile, the upper shoreface rises gently to the forebeach, which is a seaward-sloping transition between the land and the sea. The back beach is commonly the site of low, unvegetated or sparsely vegetated coppice mounds or wind-shadow dunes.

*Coppice dunes* represent the initial stage of dune accretion and are a source of sand that can be exchanged with the beach during storms. They form by accumulation of sand on the downwind side of vegetation or other small irregularities on the beach. In their later stages of development, they may become more vegetated and stabilized.

*Discontinuous vegetated fore-island dunes* are common behind the coppice dune area, and in front of the first foredune ridge. On northern Mustang Island, they reach heights of 15 feet above sea level.

During storms, steep plunging waves erode the upper beach, coppice mounds, and discontinuous foredunes, transporting the sand in a seaward direction. The net effect is to produce a broad hurricane beach. In this way, the storm-wave energy is dissipated over a large area, and the erosive energy focused on any one spot is decreased. The dunes become flattened, but the sand is merely moved out onto the beach and shoreface to compensate for the increased wave heights and energy. The discontinuous, hummocky foredunes also dissipate wave and current energy by offering resistance to the flow of water across the area between the beach and foredune ridge. Given the right conditions, these dunes will build back after the storm.

The *continuous fore-island dune ridge* on Mustang Island rises sharply from the hummocky foredune zone. This seaward-facing wave-cut cliff is a remnant from past hurricanes with surge heights capable of eroding the ridge. The continuous dune ridge also serves as a barrier to block storm surge and prevent it from washing onto the back-island area. Behind the foredune ridge is a gently sloping back-dune ramp that extends onto the vegetated barrier flat.

After a storm has passed, beach and dune recovery begins almost immediately. Within several days after Hurricane Fern (1971), the shoreward migration of small swash bars was observed as the sand transported offshore during the beach flattening process began to return. These were later observed welding to the lower beach (Davis, 1972).

After Hurricane Celia (1970), McGowen and others (1970) observed the onshore transport of sand lost during the storm and the restoration of the normal beach profile. Hayes (1967) reported the formation of a broad hurricane beach by Carla (1961) which, in places on Mustang Island, eroded the foredunes 300 feet from their former position and left wave-cut cliffs up to 15 feet high in the foredune ridge. After the storm, Hayes (1967) observed the return of the wind-shadow dunes on the back beach and the subsequent repair of the foredune ridge. Thus, the beach and dunes have a natural means by which they adjust to storm surge so as to minimize its erosive potential. The dunes are critically important to both high- and low-profile islands: as a sand supply to allow the beach to adjust during storms and as buffers that can dissipate wave energy and eventually recover or become reestablished. Where the dunes are continuous and unbreached, they act as a last defense against storm surge.

There are several ways in which the dunes can become breached. In areas where the foredunes have become weakened by devegetation and deflation or where roads and paths have been cut through the dunes, an easy pathway has been provided for storm-surge waters. Examination of aerial photographs of Mustang Island reveals that storm washovers have breached the foredunes in several places.

*Active dunes and blowouts* have been initiated in several of these storm washovers (pl. 1). Many are still active in the form of large unvegetated sand sheets that have migrated westward from the foredune zone. This unvegetated sand is not as effective as the vegetated foredunes in blocking storm surge because it is easily eroded, and the low deflation plain that is left behind as the active sand migrates becomes a potential washover site. The deflation plain offers relatively little resistance to storm surge and is of a particularly serious nature when it occurs in the foredune ridge.

*Stable blowouts* are hummocky, vegetated surfaces that are the remnants of active blowouts and deflation plains. These stable blowouts may become reactivated if the stabilizing vegetation is destroyed.

*Back-island dunes* on Mustang Island occur along the margin of Corpus Christi Bay and Laguna Madre and offer flood protection from bay surges and flood runoff.

## Distribution of Dune Types

To examine the beach-dune complex on Mustang Island, 21 profiles were prepared at intervals of approximately 5,000 feet between the south jetty of Aransas Pass and Packery Channel (fig. 1). These profiles (fig. 24) were prepared from U.S. Geological Survey 7-1/2 minute quadrangle topographic maps and were checked using 1974 aerial photographs and field observations. The profiles indicate that, in addition to the variations in dunes shown along a transect from the Gulf to the bay, variation in the distribution of dune types is present along the length of the island. From Aransas Pass south to a point 2,600 feet north of Beach Access Road 1A (see profiles 1-3), the island has a very wide beach, a series of coppice mounds on the back beach, a broad zone of vegetated discontinuous foredunes, two foredune ridges with an intervening broad swale, and a gently sloping backdune ramp extending onto the vegetated barrier flat. The two dune ridges are roughly parallel to each other and are at a slight angle to the shoreline, which brings them closer to the beach southward. At the north end of the island (profile 1), the first dune ridge is 1,500 feet from mean high tide, leaving a wide zone of hummocky foredunes between the ridge and the Gulf. At profile 3, however, the first dune ridge is only 400 feet from mean high tide. In this area, the dune ridge becomes more critical as storm protection for the island because there is less area between the ridge and the Gulf over which storm energy can be dissipated. Thus, the dune ridge will receive a stronger storm surge than the ridge farther to the north.

At a point 2,600 feet north of Access Road 1A, the second dune ridge has been washed back over Park Road 53 and does not continue down the island south of this point. There are two locations on the island where an isolated second dune ridge does occur, however. The first site is at profile station 5, where the coppice mounds and hummocky foredunes have coalesced to form a second ridge seaward of the first continuous dune ridge. The second site, 1,000 feet south of profile station 10, also exhibits a hummocky second ridge landward of the first continuous dune ridge. There are several places where it appears from the profiles that there are two dune ridges, but the profile merely transected a low area within the continuous dune ridge (profile 9) or across an isolated hummocky foredune seaward of the continuous ridge (profile 4).

South of profile 3, the first dune ridge is parallel to the shoreline, but the hummocky foredunes and the coppice mounds occur in a narrow band between the beach and the dune ridge. In map view, the Gulf side of the ridge is a straight line, but the back side of the ridge has an uneven boundary with the back dune ramp which extends toward the bay. This irregularity is caused by the numerous small washovers and blowouts that have breached the ridge in the past and have since become healed.

Profile 6, near a large active blowout, shows the absence of a prominent dune ridge and the hummocky nature of the foredunes. The sand has become devegetated and blown back across the island toward Park Road 53 in a broad, flat sheet by onshore winds.

Profile 7 transects an area where the foredune ridge became devegetated, displaced toward the bay several hundred feet, and revegetated, leaving a deflation plane between it and the Gulf. Since that time, a line of coppice mounds has developed in the deflation plane between the displaced ridge and the Gulf. Profile 8 is also across a blowout area; the devegetated sand has blown back to Park Road 53, where it forms a steep avalanche face at its most bayward extension.

A large washover fan is located 1,800 feet north of profile 12 and the fore-island dunes have been breached at this point.

South of Access Road 2A (profile 12), the fore-island dunes are more hummocky, and the continuous ridge is less distinct and more irregular than to the north. This irregular ridge attains heights of 15 feet or more above sea level (profiles 16, 18, 20), but active blowouts are more numerous between these high points. Broad washover plains

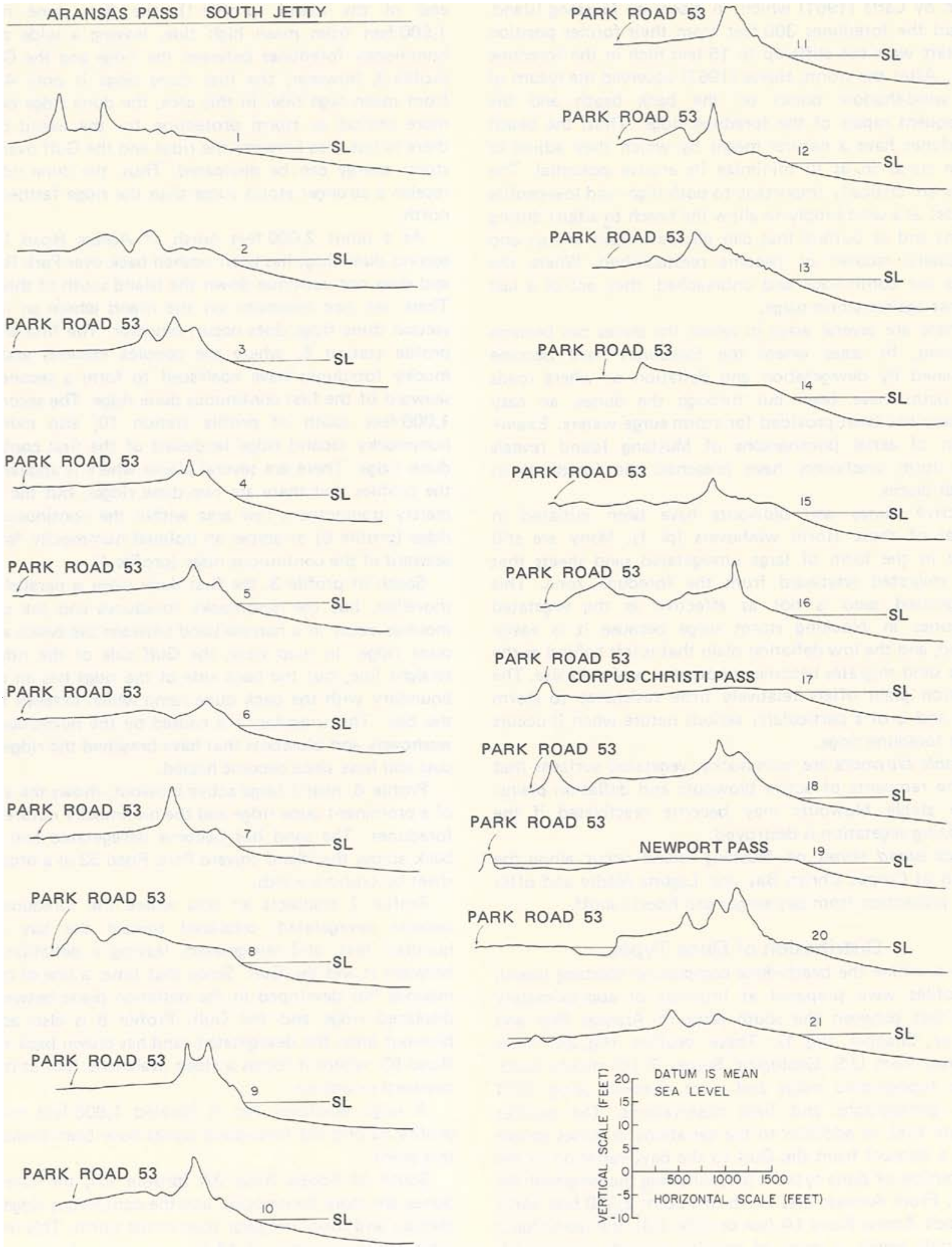



Figure 24. Dune profiles of Mustang and north Padre Islands.

with numerous coppice mounds are located on the north and south sides of the Gulf entrance to the fish pass. These areas appear as beach and coppice mounds on plate 1. Landward of the washover plains are active dune and blowout fields. Profile 14 transects the washover plain and blowout field south of the fish pass. This area becomes flooded during storms, and the coppice mounds are destroyed. Between storms, they build back, but salt-water flooding limits the growth of vegetation on the washover plain and the blowout field.

Corpus Christi Pass (profile 17) and Newport Pass (profile 19) are broad duneless washover channels flanked by deflation plains. There are, however, well developed fore-island dunes between the passes (profiles 18, 20, 21).

From Packery Channel south to the Nueces County line, the fore-island dunes have been breached by numerous washovers and several extensive blowouts. The foredunes offer local protection from storm flooding, but because of their discontinuous nature, are subject to storm breaching.

## CONSTRAINTS ON DUNE DEVELOPMENT

There are three important interrelated sets of factors to consider in determining dune criticality. The first is the type of island under consideration. As previously mentioned, high- and low-profile islands respond differently to the forces of storm water; the types of dunes present and their response to storms dictate general guidelines for the type of development that can occur—based on the extent of washover and flooding that can be expected. Secondly, more detailed site-specific information can be based on the individual dune types present. Different types of dunes serve different functions in protecting residential and commercial developments, as well as the natural environment, from storms. Thirdly, dune characteristics such as continuity and orientation, height, amount of vegetation (degree of stabilization) and location with respect to the Gulf, washover passes, blowout, and population centers are important considerations.

### Type of Island

Mustang and north Padre Islands are relatively stable, sand-rich high-profile islands located on a sand-rich Pleistocene strandplain in the vicinity of present-day longshore drift convergence along the Texas coast. There is an adequate supply of sand to build high continuous dunes, low, hummocky discontinuous dunes, and coppice mounds. There is also sufficient rainfall to allow vegetation to grow and stabilize the dunes. Consequently, these dune systems are among the best found anywhere along the Texas coast. The shoreline of Mustang Island is relatively stable compared to other segments of the coast; although the island has been flooded by recent storms, major washovers are confined to the Corpus Christi - Newport - Packery Channel complex.

### Dune Types

A chart summarizing the developmental suitability of the various dune environments is presented in table 7. Each of the environments has been evaluated according to its suitability for six land uses: (1) conservation and preservation, (2) passive recreation, (3) active recreation, (4) low development density, (5) high development density, and (6) traffic routing (Wallace and others, 1971). Each environment is rated as undesirable, a possible problem area, or suitable for each of these land uses based on potential hazards to life and property as well as possible interference with the natural systems of the island. Each rating presented is conservative, and, in reality, the suitability of each dune type for the activities described is influenced by site-specific characteristics of the dunes being considered. (See the following discussion on dune characteristics.)

The fore-beach and back-beach areas are suitable for conservation and passive recreation only. Any solid structures in this area are subject to destruction by even minor storms (Morton, 1976). Seawalls may be detrimental because solid structures on the beach not only prevent the exchange of sand with the dunes, but they form a solid bulkhead in the surf zone against which storm waves break. This concentrates the wave energy on the back beach in front of the seawall and the rapid back-rush of water carries the beach sand offshore. There is no broad beach on which storm waves can dissipate their energy, and no reserve sand supply for the beach. The U.S. Army Corps of Engineers (1971b) has stated that although "seawalls may protect the upland, they do not hold or protect the beach which is the greatest asset of shorefront property."

Table 7. Suitability of dune types for specific activities (land use designations after Wallace and others, 1971).

| Environment | Land Use C | PR | AR | D1 | D2 | T |
|---|---|---|---|---|---|---|
| Forebeach | + | + | x | x | x | x |
| Backbeach | + | + | o | x | x | x |
| Coppice mounds | + | o | x | x | x | x |
| Hummocky foredunes (discontinuous) | + | o | x | x | x | x |
| First foredune ridge | + | x | x | o | x | x |
| Swale between dune ridges | + | o | o | o | o | o |
| Second foredune ridge | + | o | x | + | o | x |
| Back dune ramp | + | + | o | + | + | o |
| Vegetated barrier flat | + | + | + | + | + | + |

**C** - Conservation and Preservation: represents areas that should not be developed because of hazards that affect both life and property as well as dangerously interfere with the natural processes active on the island.
**PR** - Passive Recreation: represents activities requiring low levels of exertion and/or minor impact on the natural systems; for example, walking, bathing, and nature observation.
**AR** - Active Recreation: represents activities requiring moderate to high levels of exertion and/or a greater intensity of developed facilities; for example, golf courses and tennis courts.
**D1** - Development Density 1: represents low density development and a low number of people per unit area. This includes well spaced single family houses.
**D2** - Development Density 2: moderate to high density development and a high number of people per unit area; for example, institutional developments (village facilities, churches, and schools) as well as residential developments (condominiums and apartment complexes).
**T** - Traffic; paths of extensive pedestrian and vehicular transportation.

+ - Suitable. o - Possible problems. x - Undesirable.

The back-beach coppice mounds and the hummocky foredunes are suitable only for conservation because of the importance of maintaining a supply of sand between the beach and the dune ridge. These are critical dunes and should not be disturbed. Pedestrian and vehicular traffic should be restricted from this area to allow the vegetation to grow and trap sand blowing off the beach. If it is necessary for pedestrian traffic to cross the coppice mounds or hummocky foredunes, elevated boardwalks should be built so that dune grass and small dunes will not be destroyed.

The first dune ridge is also critical because it protects the back-island area from being washed over by most storms. It may also serve as an additional sand supply for beach adjustments during storms. Pedestrian and vehicular traffic should be restricted from crossing the dune ridge because such activities may destroy dune grass and initiate blowouts which can weaken the ridge. The first dune ridge is particularly critical south of Beach Access Road 1A, where it is the only ridge present, and is closer to the Gulf than either ridge to the north.

The criticality of a second dune ridge (where it occurs) is partly determined by the condition of the first ridge. In areas where the first ridge is low or has been weakened by blowouts or washovers, the second ridge becomes more critical than in areas where the first ridge is high and unbreached. In either case, the density of developed facilities should be kept at a minimum.

The swale between the two ridges (where it occurs) is a hazardous area to develop because it is susceptible to flooding and water may pond in the low area after even minor storms. Elevated structures are advisable.

The most advisable area to develop with respect to the safety of life and property as well as preservation of the island's natural systems is the back-dune ramp and vegetated barrier flat. The gently bayward sloping ramp is elevated above the vegetated barrier flat and is relatively protected from bayside flooding. The ramp is landward of the fore-island dunes and is therefore protected from most direct storm-surge action. If the vegetation is not destroyed, the ramp is stable. Passage to and from the beach can best be accomplished by elevated walkways over the dunes.

Construction in dune breaches should be avoided because they become potential washover sites. The washover vulnerability of the breach is a function of its elevation above sea level and the distance of the breached dunes from the Gulf.

## Dune Characteristics

The last step in determining dune criticality is to consider the site-specific characteristics of each of the dune types previously discussed.

Dune continuity is an important characteristic because a continuous ridge of dunes protects back-island areas from hurricane surge and washover more effectively than do discontinuous dunes. The best protection is offered by a combination of a high, continuous dune ridge with discontinuous dunes seaward. If they are extensive enough, these discontinuous hummocky foredunes can dissipate storm surge before it reaches the continuous dune ridge.

Dunes oriented with their long axis parallel to the shoreline are most effective in blocking high storm waters and sheltering back dune areas from high winds. Dunes with their long axis perpendicular to the shore could actually funnel storm surge into interdune areas.

Dune height and width are also important characteristics. Studies by the Corps of Engineers indicate that hurricane surge rarely exceeds 15 feet along the Texas coast. High, wide dunes are much more effective as storm protection than are low, narrow dunes.

The amount of vegetative cover is another factor to consider. Surface vegetation acts as a baffle to trap blowing sand and the extensive underground root systems of dune grasses act as binding agents to retard the movement of loose sand exposed to erosion by wind and water.

There has been some debate as to whether vegetated dunes are more critical than nonvegetated dunes when, in fact, they both serve an important function. There are shoreline segments where the only dunes present are unvegetated blowout dunes and here they become critical to the areas behind them. Both vegetated and devegetated dunes are important, although vegetated dunes are more desirable as storm protection because of their stability.

The deflation flat left by migrating dunes may be a potential washover site. Devegetated areas may be more desirable for the location of developed facilities that otherwise would require the leveling of vegetated dunes. This is particularly true if the developer initiates a dune-stabilization program in a devegetated area.

Location with respect to the Gulf is important because dunes farther back from the water are generally less vulnerable to storm attack than those that are closer. The increased distance from the Gulf also affords a greater area for wave and current dissipation before storm waters reach the dune ridge. On Mustang Island, the foredunes just south of the jetty at Aransas Pass are farther back from the Gulf than those to the south and are therefore less critical.

Dunes located near washover passes are very likely to be leveled during storms and high tides. Examples are the coppice dunes bordering Corpus Christi, Newport, and Packery Channels and the fish pass.

## Ordinal Ranking of Dunes

Conclusions concerning dune criticality must be based not only on the type of island, type of dunes, and dune characteristics, but also on the function that the dunes serve. To state that continuous dunes are more critical than discontinuous dunes is misleading because each serves a different function; if only discontinuous dunes are present, they become most critical.

A ranking of dune criticality based on the role that each type plays in conjunction with other dune types is as follows:

1. High vegetated continuous fore-island dune ridges.
2. High *un*vegetated continuous fore-island dune ridges.
3. High vegetated *dis*continuous fore-island dunes.
4. High *un*vegetated discontinuous fore-island dunes.

5.-8. Same as points 1 to 4, but low elevation (< 10 feet).

9. Vegetated coppice mounds.
10. Vegetated coppice mounds occurring seaward of continuous fore-island dunes or discontinuous foredunes.

11. Sparsely vegetated coppice mounds.
12. Sparsely vegetated sand flats.
13. Unvegetated sand flats.

This ranking will vary according to location on the coast and the specific conditions that prevail at any particular time and place. The ranking is most applicable to Mustang Island. It should be apparent that dunes offer the best storm protection where there is more than one dune type present and are most critical when one type occurs alone.

## PUBLIC BEACH ACCESS AND DUNE STABILITY

Unique political and social conditions in Texas permit practically unlimited access to much of the Gulf shoreline. Although access to the Gulf beaches is controlled, the traffic up and down the beach is not controlled except by speed limits and certain restrictions on driving along the "wet" beach. In Texas, increased demands for recreation partially translate to increased beach traffic.

In the preceding discussion the function and importance of the fore-island dunes in geological processes and natural hazards have been emphasized. Equally important is an understanding of alterations in the natural beach-dune system as a result of increased use of the beach, especially in the vicinity of the fore-island dunes. Unfortunately, little has been done to prevent adverse effects of beach maintenance and vehicular traffic: perhaps this neglect may be attributed to the lack of published data on the subject. The barrier islands, in particular the beach and foredunes, have experienced a gradual transition from nearly opposite extremes in degree of use. During the past 40 years, beach traffic and beach maintenance has increased from only occasional occurrences with no adverse effect to practically continuous use and maintenance with possible unforeseen impact on dune stability.

The Gulf beaches in and immediately adjacent to the study area provide a spectrum of natural and humanly altered conditions. Beach grading does not occur on San Jose Island, and beach traffic is limited to daily reconnaissance and those few trips essential for ranch operation. Because such limited traffic is generally confined to the "wet" beach, there is no observed effect on the back beach or dunes. The other end member is represented by the study area, Mustang and north Padre Islands. Along this segment of the coast, beach grading occurs in park areas, and driving on the back beach is not only permitted but is also encouraged to avoid possible conflict between beach traffic and beach recreation. An intermediate state exists on north Padre Island in which a segment of Padre Island National Seashore has been closed to beach traffic since 1968. Prior to acquisition by the National Park Service, this segment of the beach supported traffic nearly equal to that in the study area.

From field observations and beach profiles it is apparent that grading and vehicular traffic along the back beach prevent the formation of coppice mounds and thus eliminate the sparse vegetation (fig. 25). The exclusion of sand

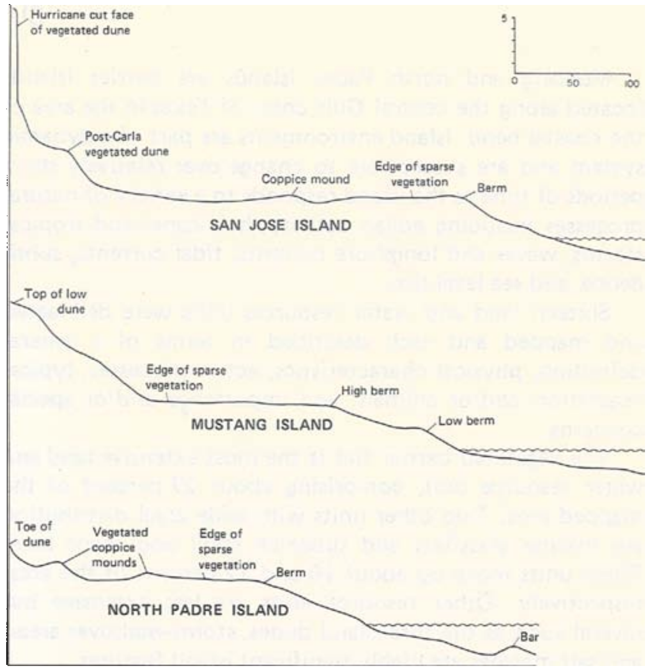



Figure 25. Beach profiles illustrating differences in beach width and position of the vegetation line in areas of vehicular and nonvehicular traffic.

accumulation and concomitant decreases in back-beach elevation permit the erosion of the fore-island dunes by lower storm-surge elevations. Furthermore, a given storm will probably inflict greater damage on the dunes because of the increased erosion anticipated as a result of the elimination of the reserve of sand.

At the present, beach grading in the study area is infrequent and is limited to removal of natural accumulations of seaweed (Sargassum) and other debris that wash ashore from the Gulf. The sand and debris scraped from the beach is usually placed in front of the dunes or in washover areas. Such activities have the same general effect as vehicular traffic with the exception that substantial volumes of sand are redistributed on the beach. Perhaps some of the post-Carla dune development and accumulation of sand attributed to snow fences and natural accumulation are partially the reflection of beach maintenance.

The heaviest beach traffic is concentrated near the break in slope between the back beach and the dunes. Therefore, beach traffic could control to some extent the position of the dunes and the vegetation line. For example, if the dunes were eroded by a major hurricane, beach traffic following the storm could prevent the recovery of the dunes and natural seaward advance that normally follows. In that case, the beach traffic would artificially maintain the dunes and vegetation line in a more landward position. Gulfside camping also occurs near the break in slope seaward of the dunes and, as a result, pedestrian traffic on the dunes is increased. The possible long-term effects of increased beach use remain questionable.

## SUMMARY

Mustang and north Padre Islands are barrier islands located along the central Gulf coast of Texas in the area of the coastal bend. Island environments are part of a dynamic system and are susceptible to change over relatively short periods of time as the island responds to a variety of natural processes including eolian activity, hurricanes and tropical storms, waves and longshore currents, tidal currents, subsidence, and sea-level rise.

Sixteen land and water resources units were delineated and mapped and each described in terms of a general definition, physical characteristics, active processes, typical vegetation and/or animals, and importance and/or special concerns.

The vegetated barrier flat is the most extensive land and water resource unit, comprising about 27 percent of the mapped area. Two other units with wide areal distribution are marine grassflats and subaerial spoil and made land. These units make up about 19 and 12 percent of the area, respectively. Other resource units are less extensive but several such as the fore-island dunes, storm-washover areas, and salt marshes are highly significant island features.

Historical changes in natural environments, Gulf and bay shorelines and the Gulf vegetation line, were determined using historical monitoring techniques which involve precise cartographic comparison and analysis of chronologic charts, maps, and photographs.

Historical monitoring revealed that significant changes occurred in natural environments on Mustang and north Padre Islands during an approximate 36-year period (1938-1974). Changes include (1) a reduction in the area occupied by eolian landforms as a result of the gradual stabilization of these areas by vegetation, (2) the spread of subaqueous grassflats into former areas of wind-tidal flats or into areas of subaqueous sand shoals occurring in washover areas, and (3) an increase in the area occupied by spoil and made land particularly in the north Padre Island area.

Historical monitoring of Gulf and bay shorelines indicates that net shoreline changes over approximately the past 100 years are predominantly erosional. Of 22 points monitored along the Gulf shoreline, net erosion was recorded at 18 points, whereas net accretion was recorded at only 4. At most points, the net rate of change was relatively low, less than 3 feet per year, but short-term changes occurred at much higher rates where the shoreline experienced both accretion and erosion. A disturbing fact is the erosional trend in the Gulf shoreline established after 1958 continued until 1974 and is probably still operative.

Bay shorelines were monitored along two major segments of Mustang Island. Net historic changes (1867 to 1974) at 19 monitoring points varied, with 11 points experiencing net erosion, 7 points net accretion, and one point no change. More recent trends, 1958 to 1974, indicate all but 1 point were experiencing erosion. The data indicate that bay shoreline erosion will probably continue at many of these points.

Changes in the position of the vegetation line along the Gulf shoreline, monitored from aerial photographs ranging in date from 1937 to 1974 indicate net accretion (encroachment toward Gulf shoreline) on Mustang and north Padre Islands at all monitoring points except one which experienced net retreat. In general, the long-term change in position of the vegetation line is similar to that of the shoreline. Short-term changes in position of the vegetation line, however, reflect climatic conditions and take place independent of shoreline changes.

Fore-island dunes were studied in more detail than other barrier-island resources because of their significant role in providing protection for back island areas and the mainland from the full force of storm surge, wave action, and flooding. Objectives of the dune study were to review the factors that are critical to the maintenance of protective dunes along coastal barrier island, to describe the various dune types on Mustang and north Padre Islands, to consider their function in responding to storms, and to describe the relative importance of each type in protecting both the natural coastal system and man's barrier-island development within that system.


## ACKNOWLEDGMENTS


Much of this report was prepared initially by the Bureau of Economic Geology (authors listed under the direction of R.A. Morton) as part of a multidisciplinary report on Mustang and north Padre Islands (Kier and Fruh, 1976). The initial report, which was reviewed by C.G. Groat, E.G. Wermund, and R.S. Kier, was one of a series concerning the Establishment of Operational Guidelines for Texas Coastal Zone Management, a project funded by the National Science Foundation, Resources Applied to National Needs Program, and the Division of Planning Coordination Office of the Governor of Texas. The project, directed by E. Gus Fruh (Environmental Health Engineering Center for Research in Water Resources), was coordinated through the Division of Natural Resources and Environment, The University of Texas at Austin.

H.E. White, Jr., and Jack Bowen of the General Land Office of Texas made valuable contributions to this report by providing the 1974 aerial photographs on which the land and water resources were mapped. Fred B. Jones of the Welder Wildlife Foundation was consulted in the identification of barrier-island plants.

In the Bureau of Economic Geology, assistance in preparation of this report was provided by the following individuals. L.F. Brown, Jr., reviewed the report and made valuable comments and suggestions. Cartographic work was performed by D.F. Scranton and R.L. Dillon. Cover and publication design was by Bobbie S. Couch. Drafting and design work was under the supervision of J.W. Macon. The manuscript was edited by C. Haynie. The manuscript was composed by Fannie Mae Sellingsloh and Kathleen A. O'Neill. David Stephens prepared photographs for publication.

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# APPENDIX A

## HISTORICAL SHORELINE MONITORING GENERAL METHODS AND PROCEDURES USED BY THE BUREAU OF ECONOMIC GEOLOGY

### Definition

Historical shoreline monitoring is the documentation of direction and magnitude of shoreline change through specific time periods using accurate vintage charts, maps, and aerial photographs.

### Sources of Data

Basic data used to determine changes in shoreline position are near-vertical aerial photographs and mosaics and topographic charts. Accurate topographic charts dating from 1850, available through the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), were mapped by the U.S. Coast Survey using plane-table procedures. Reproductions of originals are used to establish shoreline position (mean high water) before the early 1930's. Aerial photography supplemented and later replaced regional topographic mosaics representing a diversity of scales and vintages. These photographs show shoreline position based on the sediment-water interface at the time the photographs were taken.

### Procedure

The key to comparison of various data needed to monitor shoreline variations is agreement in scale and adjustment of the data to the projection of the selected map base; U.S. Geological Survey 7.5-minute quadrangle topographic maps (1:24,000 or 1 inch = 2,000 feet) are used for this purpose. Topographic charts and aerial photographs are either enlarged or reduced to the precise scale of the topographic maps. Shorelines shown on topographic charts and sediment-water interface mapped directly on sequential aerial photographs are transferred from the topographic charts and aerial photographs onto the common base map mechanically with a reducing pantograph or optically with a Saltzman projector. Lines transferred to the common base map are compared directly, and measurements are made to quantify any changes in position with time.

### Factors Affecting Accuracy of Data

Documentation of long-term changes from available records, referred to as *historical monitoring*, involves repetitive sequential mapping of shoreline position using coastal charts (topographic surveys) and aerial photographs. This is in contrast to short-term monitoring which employs beach profile measurements and/or the mapping of shoreline position on recent aerial photographs only. There are advantages and disadvantages inherent in both techniques.

Long-term historical monitoring reveals trends which provide the basis for projection of future changes, but the incorporation of coastal charts dating from the 1850's introduces some uncertainty as to the precision of the data. In contrast, short-term monitoring can be extremely precise. However, the inability to recognize and differentiate long-term trends from short-term changes is a decided disadvantage. Short-term monitoring also requires a network of stationary, permanent markers which are periodically reoccupied because they serve as a common point from which future beach profiles are made. Such a network of permanent markers and measurements has not been established along the Texas Coast, and even if a network were established, it would take considerable time (20 to 30 years) before sufficient data were available for determination of long-term trends.

Because the purpose of shoreline monitoring is to document past changes in shoreline position and to provide basis for the projection of future changes, the method of long-term historical monitoring is preferred.

### Original Data

*Topographic surveys.*—Some inherent error probably exists in the original topographic surveys conducted by the U.S. Coast Survey [U.S. Coast and Geodetic Survey, now called National Ocean Survey]. Shalowitz (1964, p. 81) states

> . . . the degree of accuracy of the early surveys depends on many factors, among which are the purpose of the survey, the scale and date of the survey, the standards for survey work then in use, the relative importance of the area surveyed, and the ability and care which the individual surveyor brought to his task.

Although it is neither possible nor practical to comment on all of these factors or to quantify the error they represent, generally the accuracy of a particular survey is related to its date; recent surveys are more accurate than older surveys. Error can also be introduced by physical changes in material on which the original data appear. Distortions, such as scale changes from expansion and contraction of the base material, caused by reproduction and changes in atmospheric conditions, can be corrected by cartographic techniques. Location of mean high water is also subject to error. Shalowitz (1964, p. 175) states ". . . location of the high-water line on the early surveys is within a maximum error of 10 meters and may possibly be much more accurate than this."

*Aerial photographs.*—Error introduced by use of aerial photographs is related to variation in scale and resolution and to optical aberrations.

Use of aerial photographs of various scales introduces variations in resolution with concomitant variations in mapping precision. The sediment-water interface can be mapped with greater precision on larger scale photographs, whereas the same boundary can be delineated with less precision on smaller scale photographs. Stated another way, the line delineating the sediment-water interface represents less horizontal distance on larger scale photographs than a line of equal width delineating the same boundary on smaller scale photographs. Aerial photographs of a scale less than that of the topographic base map used for compilation create an added problem of imprecision because the mapped line increases in width when a photograph is enlarged optically to match the scale of the base map. In contrast, the mapped line decreases in width when a photograph is reduced optically to match the scale of the base map. Furthermore, shorelines mechanically adjusted by pantograph methods to match the scale of the base map do not change in width. Fortunately, photographs with a scale equal to or larger than the topographic map base can generally be utilized.

Optical aberration causes the margins of photographs to be somewhat distorted and shorelines mapped on photographic margins may be a source of error in determining shoreline position. However, only the central portion of the photographs are used for mapping purposes, and distances between fixed points are adjusted to the 7.5-minute topographic base.

Meteorological conditions prior to and at the time of photography also have a bearing on the accuracy of the documented shoreline changes. For example, deviations from normal astronomical tides caused by barometric pressure, wind velocity and direction, and attendant wave activity may introduce errors, the significance of which depends on the magnitude of the measured change. Most photographic flights are executed during calm weather conditions, thus eliminating most of the effect of abnormal meteorological conditions.

### Interpretation of Photographs

Another factor that may contribute to error in determining rates of shoreline change is the ability of the scientist to interpret correctly what he or she sees on the photographs. The most qualified aerial photograph mappers are those who have made the most observations on the ground. Some older aerial photographs may be of poor quality, especially along the shorelines. On a few photographs, both the beach and swash zone are bright white (albedo effect) and cannot be precisely differentiated; the shoreline is projected through these areas, and, therefore, some error may be introduced. In general, these difficulties are resolved through an understanding of coastal processes and a thorough knowledge of factors that may affect the appearance of shorelines on photographs.

Use of mean high-water line on topographic charts and the sediment-water interface on aerial photographs to define the same boundary is inconsistent because normally the sediment-water interface is almost always seaward of the mean high-water line. This displacement depends on the tide cycle, slope of the beach, and wind direction when the photograph was taken. The combinations of factors on the Gulf shoreline which yield the greatest horizontal displacement of the sediment-water interface from mean high water are low tide conditions, low beach profile, and strong northerly winds. Field measurements indicate that along the Texas Gulf Coast, maximum horizontal displacement of a photographed shoreline from mean high-water level is approximately 125 feet under these same conditions. Because the displacement of the photographed shoreline is almost always seaward of mean high water, shoreline changes determined from comparison of mean high-water line and sediment-water interface will slightly underestimate rates of erosion or slightly over-estimate rates of accretion.

### Cartographic Procedure

*Topographic charts.*—The topographic charts are replete with a 1-minute-interval grid; transfer of the shoreline position from topographic charts to the base map is accomplished by construction of a 1-minute-interval grid on the 7.5-minute topographic base map and projection of the chart onto the base map. Routine adjustments are made across the map with the aid of the 1-minute-interval latitude and longitude cells. This adjustment is necessary because: (1) chart scale is larger than base map scale; (2) distortions (expansion and contraction) in the medium (paper or cloth) of the original survey and reproduced chart previously discussed require adjustment; and (3) paucity of culture along the shore provides limited horizontal control.

*Aerial photographs.*—Accuracy of aerial photograph mosaics is similar to topographic charts in that quality is related to vintage; more recent mosaics are more accurate. Photograph negative quality, optical resolution, and techniques of compiling controlled mosaics have improved with time; thus, more adjustments are necessary when working with older photographs.

Cartographic procedures may introduce minor errors associated with the transfer of shoreline position from aerial photographs and topographic charts to the base map. Cartographic procedures do not increase the accuracy of mapping; however, they tend to correct the photogrammetric error inherent in the original materials such as distortions and optical aberrations.

### Measurements and Calculated Rates

Actual measurements of linear distances on maps can be made to one-hundredth of an inch which corresponds to 20 feet on maps with a scale of 1 inch - 2,000 feet (1:24,000). This detail is more precise than the significance of the data warrants. However, problems do arise when rates of change are calculated because: (1) time intervals between photographic coverage are not equal; (2) erosion or accretion is assumed constant over the entire time period; and (3) multiple rates ($\frac{n^2 - n}{2}$, where n represents the number of mapped shorelines) can be obtained at any given point using various combinations of lines.

The beach area is dynamic, and changes of varying magnitude occur continuously. Each photograph represents a sample in the continuum of shoreline changes, and it follows that measurements of shoreline changes taken over short time intervals would more closely approximate the continuum of changes because the procedure would approach continuous monitoring. Thus, the problems listed above are interrelated, and solutions require the averaging of rates of change for discrete intervals. Numerical ranges and graphic displays are used to present the calculated rates of shoreline change.

Where possible, dates when individual photographs actually were taken are used to determine the time interval needed to calculate rates, rather than the general date printed on the mosaic. Particular attention is also paid to the month, as well as the year of photography; this eliminates an apparent age difference of one year between photographs taken in December and January of the following year.

## Justification of Method and Limitations

The methods used in long-term historical monitoring carry a degree of imprecision, and trends and rates of shoreline changes determined from these techniques have limitations. Rates of change are to some degree subordinate in accuracy to trends or direction of change; however, there is no doubt about the significance of the trends of shoreline change documented over more than 100 years. An important factor in evaluating shoreline changes is the total length of time represented by observational data. Observations over a short period of time may produce erroneous conclusions about the long-term change in coastal morphology. For example, it is well established that landward retreat of the shoreline during a storm is accompanied by sediment removal; the sediment is eroded, transported, and temporarily stored offshore. Shortly after storm passage, the normal beach processes again become operative and some of the sediment is returned to the beach. If the shoreline is monitored during this recovery period, data would indicate beach accretion; however, if the beach does not accrete to its prestorm position, then net effect of the storm is beach erosion. Therefore, long-term trends are superior to short-term observations. Establishment of long-term trends based on changes in shoreline position necessitates the use of older and less precise topographic surveys. The applicability of topographic surveys for these purposes is discussed by Shalowitz (1964, p. 79) who stated:

> There is probably little doubt but that the earliest records of changes in our coastline that are on a large enough scale and in sufficient detail to justify their use for quantitative study are those made by the Coast Survey. These surveys were executed by competent and careful engineers and were practically all based on a geodetic network which minimized the possibility of large errors being introduced. They therefore represent the best evidence available of the condition of our coastline a hundred or more years ago, and the courts have repeatedly recognized their competency in this respect . . . .

Because of the importance of documenting changes over a long time interval, topographic charts and aerial photographs have been used to study beach erosion in other areas. For example, Morgan and Larimore (1957), Harris and Jones (1964), El-Ashry and Wanless (1968), Bryant and McCann (1973), and Stapor (1973) have successfully used techniques similar to those employed herein. Previous articles describing determinations of beach changes from aerial photographs were reviewed by Stafford (1971) and Stafford and others (1973).

Simply stated, the method of using topographic charts and aerial photographs, although not absolutely precise, represents the best method available for investigating long-term trends in shoreline changes.

Limitations of the method require that emphasis be placed first on *trend* of shoreline changes with rates of change being secondary. Although rates of change from map measurements can be calculated to a precision well beyond the limits of accuracy of the procedure, they are most important as *relative* values; that is, do the data indicate that erosion is occurring at a few feet per year or at significantly higher rates. Because sequential shoreline positions are seldom exactly parallel, in some instances it is best to provide a range of values such as 10 to 15 feet per year. As long as users realize and understand the limitations of the method of historical monitoring, results of sequential shoreline mapping are significant and useful in coastal zone planning and development.

## Sources and Nature of Supplemental Information

Sources of aerial photographs, topographic charts, and topographic base maps used for this report are identified in appendix B. Additional information was derived from miscellaneous reports published by the U.S. Army Corps of Engineers and ground measurements and observations, including beach profiles, prepared as a part of this investigation.

Relative wave intensity, estimated from photographs, and the general appearance of the beach dictate whether or not tide and weather bureau records should be checked for abnormal conditions at the time of photographs. Most flights are executed during calm weather conditions, however. On the other hand, large-scale changes are recorded immediately after the passage of a tropical storm or hurricane. For this reason, photograph dates have been compared with weather bureau records to determine the nature and extent of tropical cyclones prior to the overflight. If recent storm effects were obvious on the photographs, an attempt was made to relate those effects to a particular event.

Considerable data were compiled from weather bureau records and the U.S. Department of Commerce (1930-1974) for many of the dates of aerial photography. These data, which include wind velocity and direction and times of predicted tidal stage, were used to qualitatively estimate the effect of meteorological conditions on position of the sediment-water interface (fig. 2).

## Monitoring of Vegetation Line

Changes in the vegetation line are determined from aerial photographs in the same manner as changes in shoreline position with the exception that line of continuous vegetation is mapped rather than sediment-water interface. Problems associated with interpretation of vegetation line on aerial photographs are similar to those encountered with shoreline interpretation because they involve scale and resolution of photography as well as coastal processes. In places, the vegetation "line" is actually a zone or transition, the precise position of which is subject to interpretation; in other places the boundary is sharp and distinct, requiring little interpretation. The problems of mapping vegetation line are not just restricted to geographic area but also involve time. Observations indicate that the vegetation line along a particular section of beach may be indistinct for a given date, but subsequent photography may show a well-defined boundary for the same area, or vice versa. In general, these difficulties are resolved through an understanding of coastal processes and a thorough knowledge of factors that affect appearance of the vegetation line on photographs. For example, the vegetation line tends to be ill-defined following storms because sand may be deposited over the vegetation or the vegetation may be completely removed by wave action. The problem of photographic scale and optical resolution in determination of the vegetation line is opposite that associated with determination of the shoreline. Mapping vegetation line is more difficult on larger scale photographs than on smaller scale photographs, particularly in areas where the vegetation line is indistinct, because larger scale photographs provide greater resolution and much more detail. Fortunately, vegetation line is not affected by processes such as tide cycle at the time the photographs were taken.

# APPENDIX B

### List of Aerial Photographs

| Date | Source of Photograph |
|---|---|
| March-April 1937 | Tobin Research, Inc. |
| November 1938 | U.S. Dept. Agriculture |
| January, March and April 1956 | U.S. Dept. Agriculture |
| January and December, 1958 to January 1959 | Tobin Research, Inc. |
| September 1961 | U.S. Army Corps of Engineers |
| June 1967 | U.S. Army Corps of Engineers |
| October 1969 to August 1970 | National Oceanic and Atmospheric Administration (NOAA) |
| October 1971 | Tobin Research, Inc. |
| June 1974 | General Land Office of Texas |

### List of Maps Used in Determining Shoreline Changes

| Date | Description | Source of Maps |
|---|---|---|
| 1867 | Topographic map 1044 | NOAA |
| 1881-82 | Topographic maps 1626 and 1628 | NOAA |

### List of 7.5-Minute Quadrangle Topographic Maps

Port Aransas, Texas
Crane Islands (southwest), Texas
Crane Islands (northwest), Texas

# APPENDIX C

## LAND USE IN THE VICINITY OF PORT ARANSAS, TEXAS

Current land use was mapped on 1974 black-and-white aerial photographs available through the General Land Office of Texas. The base for the map is the same as that of the Land and Water Resources Map (pl. 1), which was adapted from U.S. Geological Survey topographic maps.

The land use map displays those areas in the vicinity of Port Aransas which were physically occupied by various types of man-made facilities in 1974. This information in conjunction with the Land and Water Resources Map, which displays spoil and made land, provides a more complete picture of man's influence on island environments.

Units mapped on the land use map are as follows:

1. Retail, commercial, and industrial facilities (includes such things as food stores, service stations, and restaurants; industrial facilities are primarily oil and gas production facilities).
2. Multiple-family residences, motels and hotels (includes condominums and apartments).
3. Single-family residences.
4. Public and private group-use facilities (includes churches, schools, Federal, State, county, and city installations and facilities and privately owned group-use facilities such as the golf course on North Padre Island).
5. Trailer parks (includes privately owned recreational vehicle parks and mobile homes).
6. Open space (includes those areas not covered by other map units; see Land and Water Resources Map for these areas).

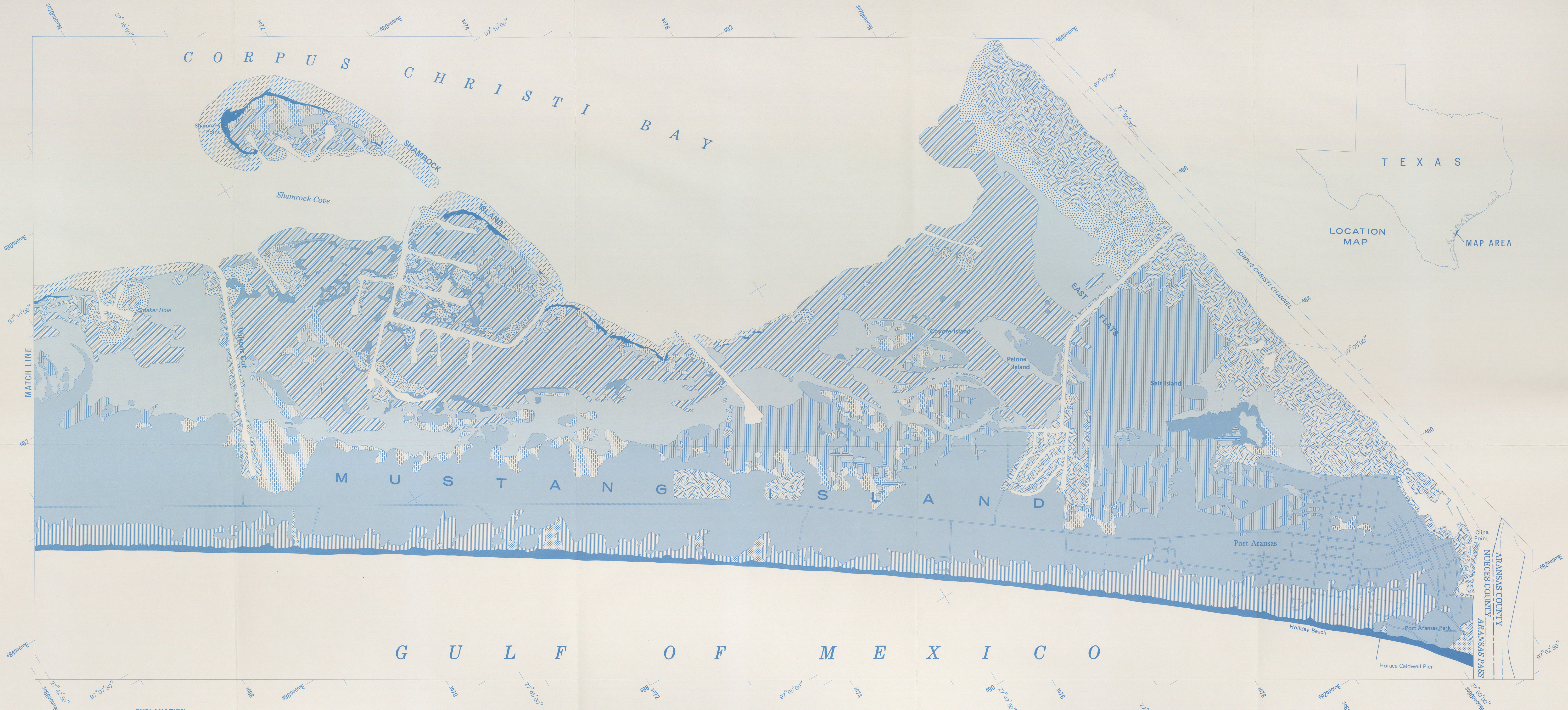

Figure C-1. Land use in the vicinity of Port Aransas, Texas.



LAND AND WATER RESOURCES, MUSTANG AND NORTH PADRE ISLANDS, TEXAS

BUREAU OF ECONOMIC GEOLOGY
THE UNIVERSITY OF TEXAS AT AUSTIN
W. L. FISHER, DIRECTOR

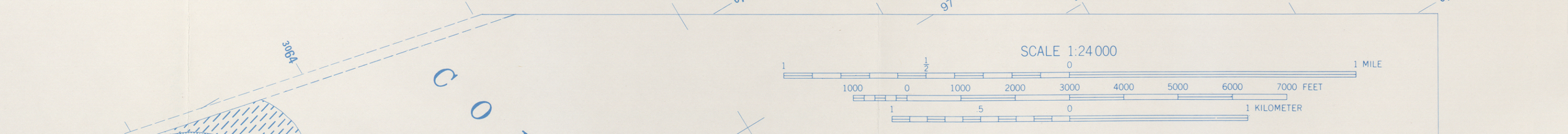





## EXPLANATION

- Beaches, coppice mounds, and wind-shadow dunes
- Vegetated fore-island and back-island dunes
- Vegetated barrier flats
- Salt marshes—*Spartina alterniflora* sparse or absent
- Grassflats
- Local sand beaches and shell berms

Mapping by Bureau of Economic Geology and Marine Science Institute, The University of Texas. Cartography by Bureau of Economic Geology. Funded by Research Applied to National Needs Program, National Science Foundation, and Division of Planning and Coordination, Office of the Governor of Texas, and coordinated through Division of Natural Resources and Environment, The University of Texas at Austin. Units mapped on 1974 aerial photos provided by General Land Office and Texas Highway Department. Base adapted from U. S. Geological Survey topographic maps. Mapping of beaches, coppice mounds, and




LAND AND WATER RESOURCES, MUSTANG AND NORTH PADRE ISLANDS, TEXAS